Petroleum Experts

IPM Tutorials

IPM 4.0

January, 2004

Tutorial Examples

The information in this document is subject to change as major improvements and/or amendments to the program are done. When necessary, Petroleum Experts will issue the proper documentation.

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1 Introduction

This document contains tutorials for the *Petroleum Experts*' software: **PROSPER, MBAL** and **GAP.** The tutorials will lead you through a number of program examples. If you are relatively new to the software, then these will allow you to use the software immediately and will provide a good overview of the programs' functionality.

The tutorials are split into two sections. The first set of tutorials is for beginners and focuses on the dexterity skills needed to use the programs. The second set focuses on the physics and engineering issues relating to the programs.

1.1 About This Guide

The guide assumes you are familiar with basic Windows operations and terminology.

The screen displays used in this guide are taken from the examples provided with the software. On occasion, the data files may vary from the examples shown as updates to the program are issued. Where major amendments or changes to the program require further explanation, the corresponding documentation will be provided.

What is in this guide:

- **Chapter 2**, 'Dexterity Examples', lists tutorials that concentrate on basic use of the programs, but do not emphasise the physics of the engineering problems concerned.

- **Chapter 3**, 'Physics Examples', lists tutorials that assume the user understands the basics of the programs, but concentrates on the physics of the engineering problems.

1.2 How to use this guide

If you have not used *Petroleum Experts*' software before you should work through all the examples in **Chapter 2** before moving on to **Chapter 3**.

If you are comfortable with using the *Petroleum Experts* software you may still find the tutorials in **Chapter 3** useful.

1.2.1 Symbols and conventions

Throughout the user guide, special fonts and/or icons are used to demonstrate specific steps, instructions and procedures in the program.

PETEX program	The term PETEX program is used when the comment is applicable to **MBAL** or **GAP**.
ALL CAPS	Represent DOS directories, file names, and commands.
Italics	Used to highlight certain points of information.
Keycap	Bold fonts are used to indicate a specific action to be taken. For example: 'Click **Done** to exit the window.'
Menu | Command	To avoid repeating the phrase 'Click the File menu and choose the Open command', we use the **File - Open** convention instead.
	Emphasises specific information to be entered or be aware of. This keyboard icon marks step-by-step instructions.
	This symbol is a reminder to click the **RIGHT** mouse button. Clicking the *right* mouse button performs specific functions in **MBAL**, depending on the active dialogue box or plot. If you do not have a right mouse button, holding down the SHIFT key while you click the mouse button performs the required function.

2 Dexterity Examples

This section contains the following tutorials:

GAP Gas Network Example:
This example builds a simple gas network system and runs a production prediction. It uses **PROSPER** to model the wells in the system and **MBAL** to model the tanks.

PROSPER Gas Well Example:
This example is used within the **GAP** Gas Network example to show how to set up the well models required in the gas network system. It can also be run in isolation.

MBAL Gas Reservoir Example:
This example is used within the **GAP** Gas Network example to show how to set up the tanks in the gas network system. It can also be run in isolation.

GAP Gas Lift Example:
This self-contained example builds and optimises an oil production system using gas lift.

2.1 GAP Gas Network Example

This tutorial example is designed to provide a step-by-step introduction to the **GAP** program. The emphasis is on the data entry required to model and analyse the production potential of a dry gas producing reservoir (no condensates). The actual data is of little importance: for clarity it has been chosen to be minimal. However, the systematic method used to generate the **GAP** model using **PROSPER** and **MBAL** is an important element of the tutorial. The **PROSPER** and **MBAL** phases are separate modules referenced from within this **GAP** tutorial.

2.1.1 STEP 1 : Initialise GAP

This section describes how **GAP** is started and how the location of the required associated files is initialised.

Start the **GAP** program by running **GAP**.EXE, which can be found in the *Petroleum Experts* directory (default C:\Program Files\Petroleum Experts\IPM 4.0). See the **GAP** manual for more details on how to start **GAP**. The version of **GAP** being used may be checked by selecting, **Help | About GAP**.

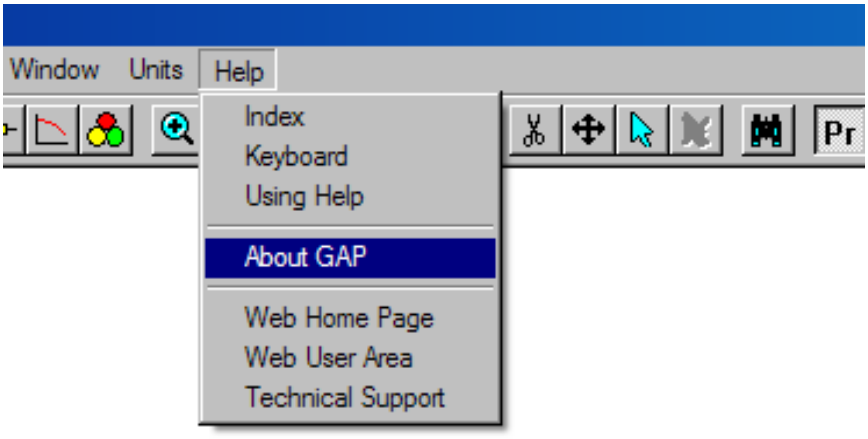


Figure 1: About **GAP** – version and build information

The command options (**File**, **Options** etc.) at the top of the **GAP** window are laid out in a logical order (left to right) that reflects the order in which operations will usually be performed. Check that **File | Directories** and check that they point to the current versions of **PROSPER** and **MBAL** respectively. It is recommended that you always use the default **Same as GAP**. The **PROSPER** and **MBAL** applications can also be found in the *Petroleum Experts* directory.

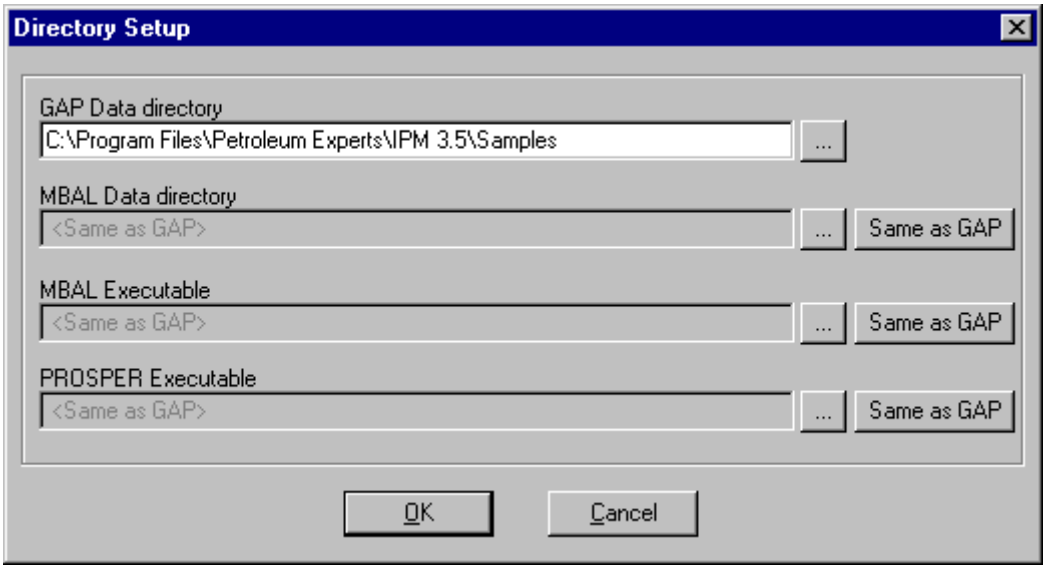


Figure 2: Directories settings

Note that files saved with these versions of **GAP**, **PROSPER** and **MBAL** *will not* be readable by previous versions. It is recommended, therefore, that the **File | Directory | GAP** and **MBAL Data Directory** options are set to point to directories that are exclusively used to store data files created with the current software versions.

When **GAP** is started a new file is initialised (unless otherwise specified in the preferences). If you wish you can ensure initialisation by selecting **File | New** or the toolbar accelerator to start a new file.

It is important to ensure that consistent units are used throughout, particularly when data generated by **PROSPER** and **MBAL** are incorporated into a **GAP** model. Oilfield units will be used for this example. Select **Options | Units** to view the units used by

GAP for input and output, the data validation ranges, and output precision. Near the top of the screen within the table heading select **Oilfield** for both input and output units (as shown in **Figure 3**), and then select **OK**.

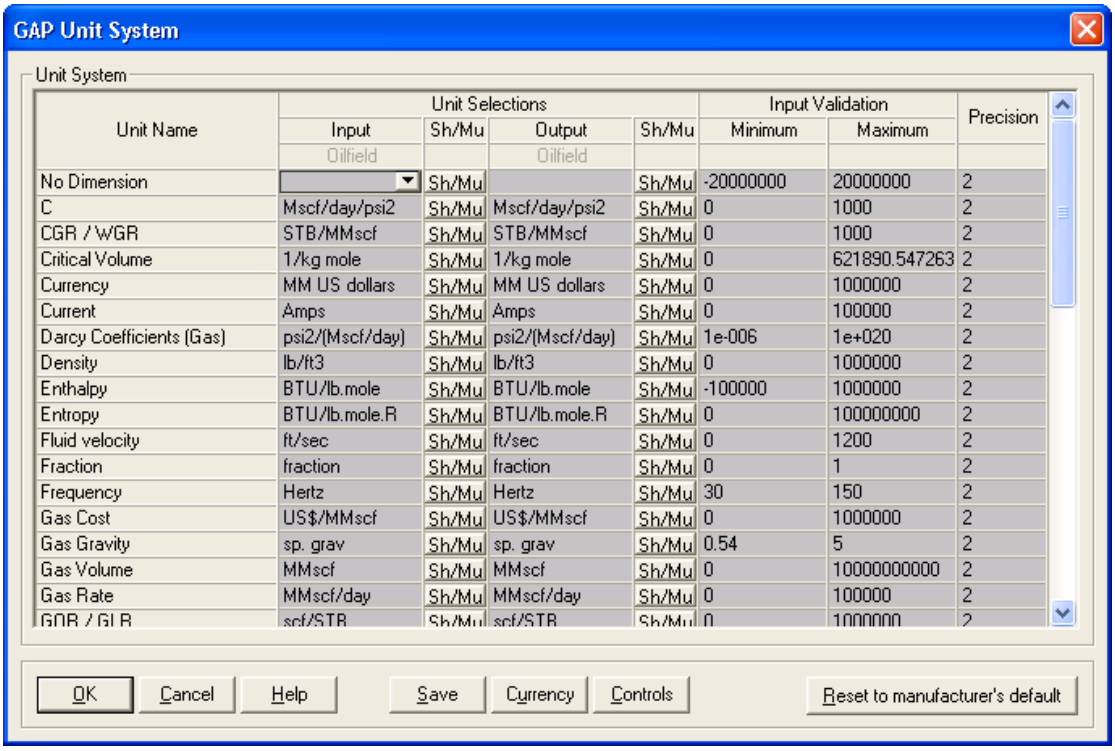

GAP Unit System
Unit System
Unit Name
Unit Selections
Input
Sh/Mu
Output
Sh/Mu
Input Validation
Minimum
Maximum
Precision
Oilfield
Oilfield
No Dimension Sh/Mu Sh/Mu -20000000 20000000 2
C Mscf/day/psi2 Sh/Mu Mscf/day/psi2 Sh/Mu 0 1000 2
CGR / WGR STB/MMscf Sh/Mu STB/MMscf Sh/Mu 0 1000 2
Critical Volume 1/kg mole Sh/Mu 1/kg mole Sh/Mu 0 621890.547263 2
Currency MM US dollars Sh/Mu MM US dollars Sh/Mu 0 1000000 2
Current Amps Sh/Mu Amps Sh/Mu 0 100000 2
Darcy Coefficients (Gas) psi2/(Mscf/day) Sh/Mu psi2/(Mscf/day) Sh/Mu 1e-006 1e+020 2
Density lb/ft3 Sh/Mu lb/ft3 Sh/Mu 0 1000000 2
Enthalpy BTU/lb.mole Sh/Mu BTU/lb.mole Sh/Mu -100000 1000000 2
Entropy BTU/lb.mole.R Sh/Mu BTU/lb.mole.R Sh/Mu 0 100000000 2
Fluid velocity ft/sec Sh/Mu ft/sec Sh/Mu 0 1200 2
Fraction fraction Sh/Mu fraction Sh/Mu 0 1 2
Frequency Hertz Sh/Mu Hertz Sh/Mu 30 150 2
Gas Cost US$/MMscf Sh/Mu US$/MMscf Sh/Mu 0 1000000 2
Gas Gravity sp. grav Sh/Mu sp. grav Sh/Mu 0.54 5 2
Gas Volume MMscf Sh/Mu MMscf Sh/Mu 0 10000000000 2
Gas Rate MMscf/day Sh/Mu MMscf/day Sh/Mu 0 100000 2
GOR / GLR scf/STB Sh/Mu scf/STB Sh/Mu 0 1000000 2
OK
Cancel
Help
Save
Currency
Controls
Reset to manufacturer's default

Figure 3: Oilfield Units for Input and Output

2.1.2 STEP 2 : Initialise GAP Method Options

In this section the scope of calculations that **GAP** will be asked to perform will be defined.

This example has a dry gas reservoir feeding a delivery pipeline 10000 ft away. No production history is available, but the extent and composition of the reservoir has been estimated, allowing a material balance prediction to be performed.

Select **Options | Method** to set the **GAP** calculation method.

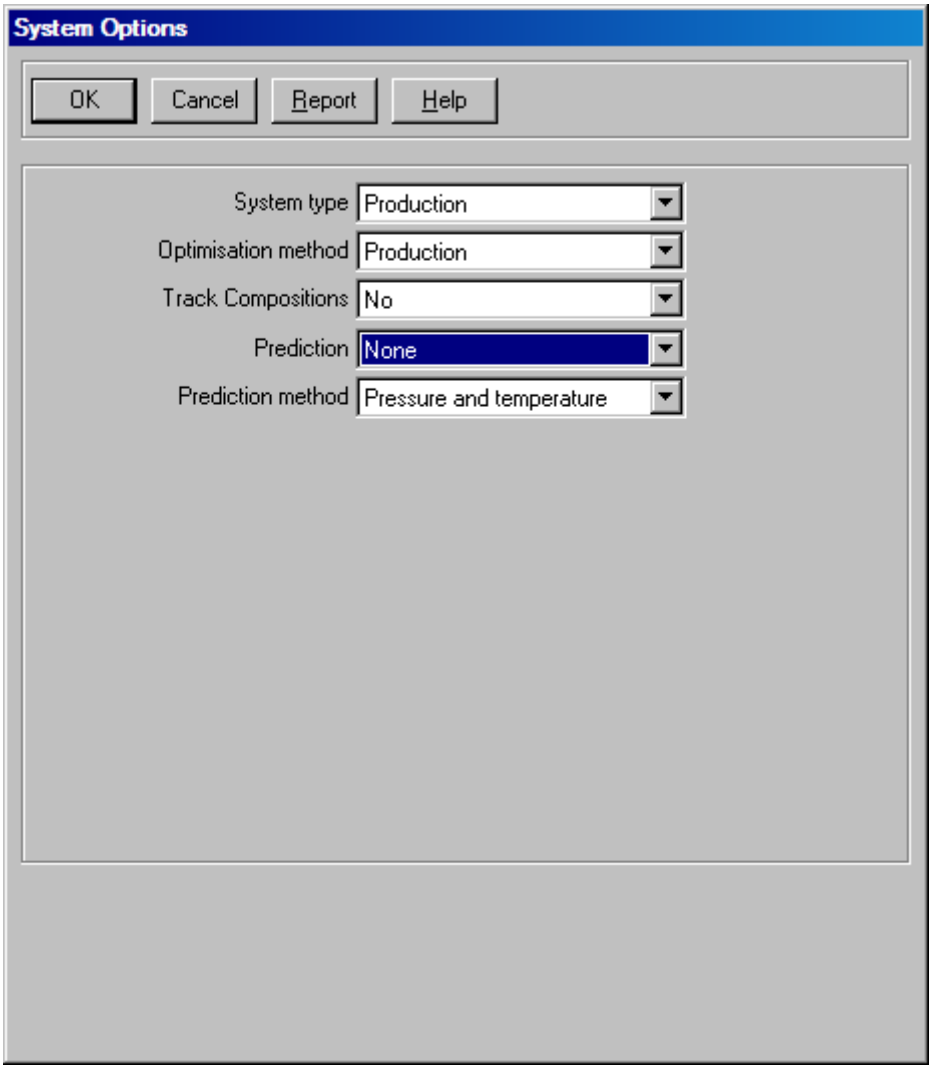


Figure 4: Setting the options

Set Prediction type to **On**. This tells **GAP** how to update reservoir pressures during a Prediction calculation. A constant reservoir pressure can be specified by selecting **None**, in which case no prediction calculations are performed: in this case, the model represents the system at an instant in time and no tank models are required. Optimisation may be performed for both predictive (depleting reservoir) and non-predictive (constant reservoir) calculations.

Set System type to **Production**, Prediction method to **Pressure and temperature**, Optimisation method to **Production**, and Track Compositions to **No**. The completed

method screen is shown above. This completes the **GAP** calculation method set-up. Select **OK** to return to the main **GAP** window.

2.1.3 STEP 3 : Define GAP Model Schematically

In this section the components required to model a simple gas production network are specified. The properties of the components and reservoir fluids are entered at a later stage using **PROSPER** and **MBAL**.

The model will consist of a reservoir tank, a gas production well and a pipeline connecting the well manifold to the delivery pipeline. It is recommended that the **GAP** model be specified from the separator (delivery pipeline) end towards the reservoir, allowing the complexity to develop naturally as the model is entered. Since this example is very simple it makes little difference in what order the components are created.

The toolbar ( ) is used to create and modify components on the network schematic. Note that when they are selected they remain active until they are unselected. The exception to this is the 'Delete' icon, which must be selected for each deletion. To identify an icon, hold the mouse cursor over it until a yellow box appears with a short description of the icon function.

Select the Separator icon and click the left-hand mouse button in the main **GAP** display area towards the top right. Give the resulting node the name 'Separator' when requested. The name is just a label and is not required, but it is generally a good idea to identify the nodes in this way. A separator is considered by **GAP** to be the end of the production chain and will be allocated a pressure at a later stage. It does not have to actually be a separator, rather a convenient delivery point where a known pressure exists.

Next, select the Joint icon and add a joint. Name this 'Manifold 1'. Place the manifold to the left of the separator. Place a second "Manifold 2" to the left of this. A joint is any manifold or intersection where pipes converge. Every pipe must have both ends connected to joints.

Select the Well icon and add a well below the Manifold 2. Name this 'Well'.

Select the Tank icon and add a Tank, named 'Tank' below the well.

Finally link the components together by selecting the Link icon and dragging the left-hand mouse button between two components. Connect the Tank to its Well, and the Well to its Manifold 2, then manifold 2 to 1 for the pipe, finally connect the Manifold 1 to the Separator. Note that a pipe component has been inserted between the two Manifolds. No pipe components have been entered between the Tank, Well, and Manifold 2 since any piping between these components is assumed to be implicitly defined by the Well.

Deselect the Link icon to prevent adding more links.

The basic model layout has been specified: additional components can easily be added or deleted as the model is refined later. The **GAP** screen display should look something like the following image.

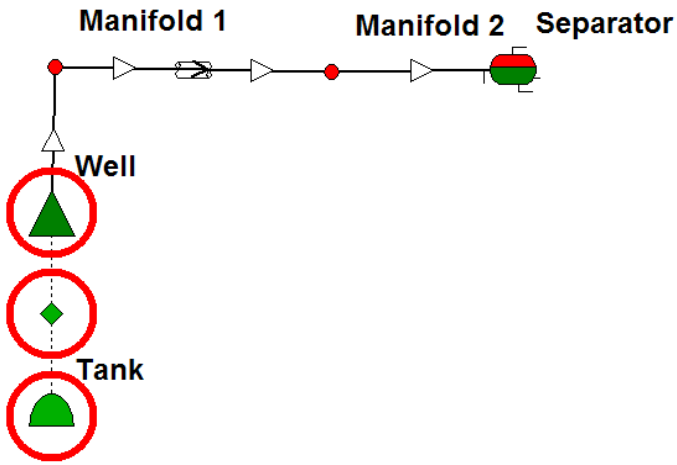


Figure 5: Schematic Network Diagram

Use **File | Save As** to save the work done this far to a **GAP** file (Gasres.**GAP**) in a suitable directory.

2.1.4 STEP 4 : Define the Well

In this step we specify the physical characteristics of the well and perforation interval that will define the flow from the reservoir to the wellhead ('Manifold' in this example). Although data may be entered directly into **GAP**, **PROSPER** will be used to enter the well properties. The advantage of using **PROSPER** is principally that the VLPs and IPRs can be generated later by automatic batch calls to **PROSPER** from **GAP**. VLPs and IPRs are elements that describe the performance of a well. We recommend the use of 'VLP/IPR Intersection' as the well model.

Please refer to the **GAP** manual for more details on well models and available options.

Additionally, matching to production history and sensitivity analysis of the well can be performed using **PROSPER**.

Double click the left-hand mouse button within the Well component on the **GAP** display screen. An Equipment Data Entry screen is then displayed. All of the model components can be seen in the right window and data entry for any component can be made by selecting the required component with a left mouse click. The red crosses show where insufficient data has been entered. Within the Well data entry screen change the Well Type to **Gas Producer** (which changes the well colour from green to red). Select the Model as **VLP / IPR Intersection**.

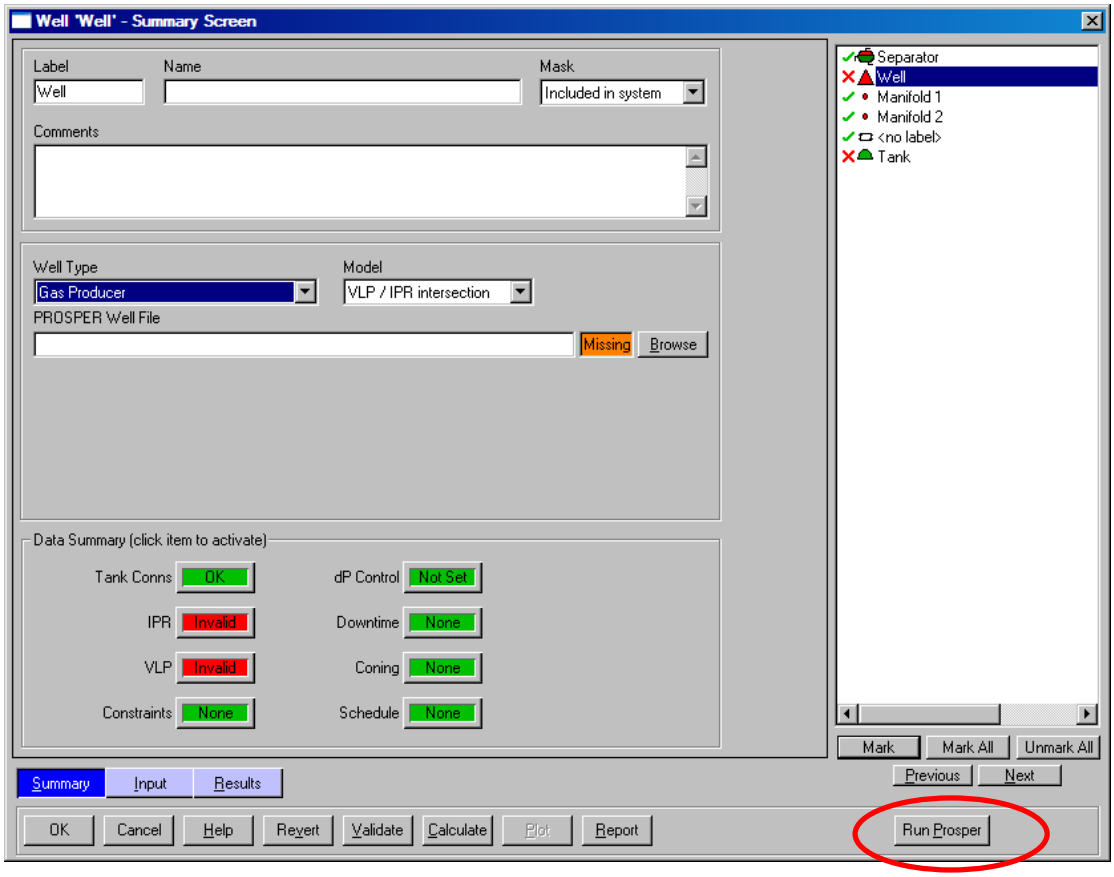


Figure 6: Equipment Data Entry Screen immediately before starting **PROSPER**

Select the "**Run PROSPER**" button and wait for **PROSPER** to load. Check that the correct version of **PROSPER** has loaded, otherwise check **File | Directory** from within **GAP**. Go to the **PROSPER** Gas Well Example (See Section 2.2 below) to set up the **PROSPER** model.

Go to the PROSPER Gas Well Example now – Section 2.2.

Once the **PROSPER** exercise is complete return to **GAP** from **PROSPER** by selecting **GAP**. It is recommended that any changes made to a **PROSPER** file are saved before returning to **GAP**.

On returning to **GAP** after creating a **PROSPER** file enter its file name in the **PROSPER** Well File field of the Equipment Data Entry screen. Use the **Browse** button to locate the file. The output (e.g. Gasres.OUT) **PROSPER** file should be used in preference to the input (Gasres.SIN) and analysis (Gasres.ANL) files. If the full drive and path to the **PROSPER** file are not entered in the Well File field, then **GAP** will look for the **PROSPER** file in the directory defined by **File | Directories**.

Notice that the status of the Well File field has changed from Invalid to Valid. To further check that the **PROSPER** file is properly located select **Run PROSPER** and then return to **GAP** by selecting **GAP** once the **PROSPER** file has loaded.

Select **OK** to return to the **GAP** main window.

Now save the **GAP** file by clicking on and selecting **Yes** to the overwrite confirmation.

2.1.5 STEP 5 : Calculate the Well IPR and VLP

The Inflow Performance Relation (IPR) and Vertical Lift Performance (VLP) data can now be generated automatically by batch calls to ***PROSPER***.

Select **Generate | Generate Well VLPs | All | Data** to specify the ranges of data for which data should be generated. ***PROSPER*** is called to load the values it already has stored. Select the **Edit** button next to the 'Well' label. Enter the following data ranges:

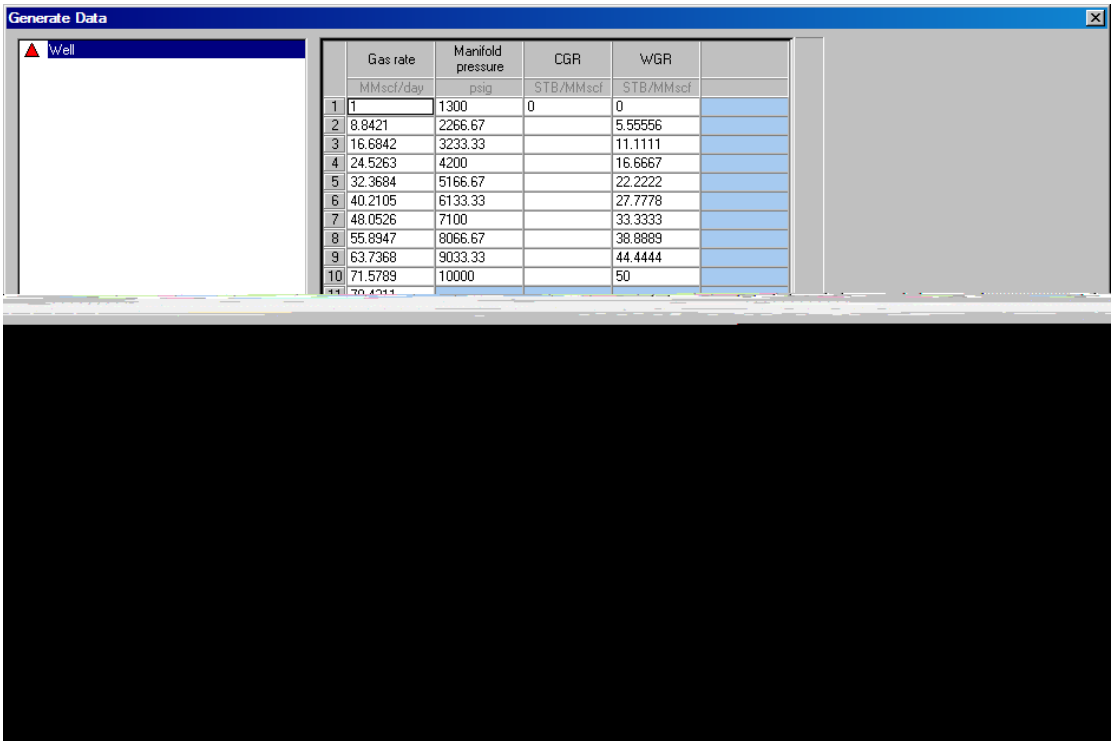


Figure 7: VLP Data Ranges

Note that the Populate buttons can be used to create the tables rather than the data being entered manually.

This table covers the range of possible gas production rates, manifold (well head) pressures and water to gas ratios (WGR) that may occur. Since the gas is a dry gas, the condensate to gas ratio (CGR) will always be 0.
Select **OK** and then **Generate** to perform the calculations using ***PROSPER***: this may take some time. Select **OK | OK** when the calculations have completed.

Go back to the main screen. Double-click on the Well icon to bring up the well summary screen. Notice that the colour of the box next to the word 'VLP' has turned green. This indicated that the VLP generation has been completed.

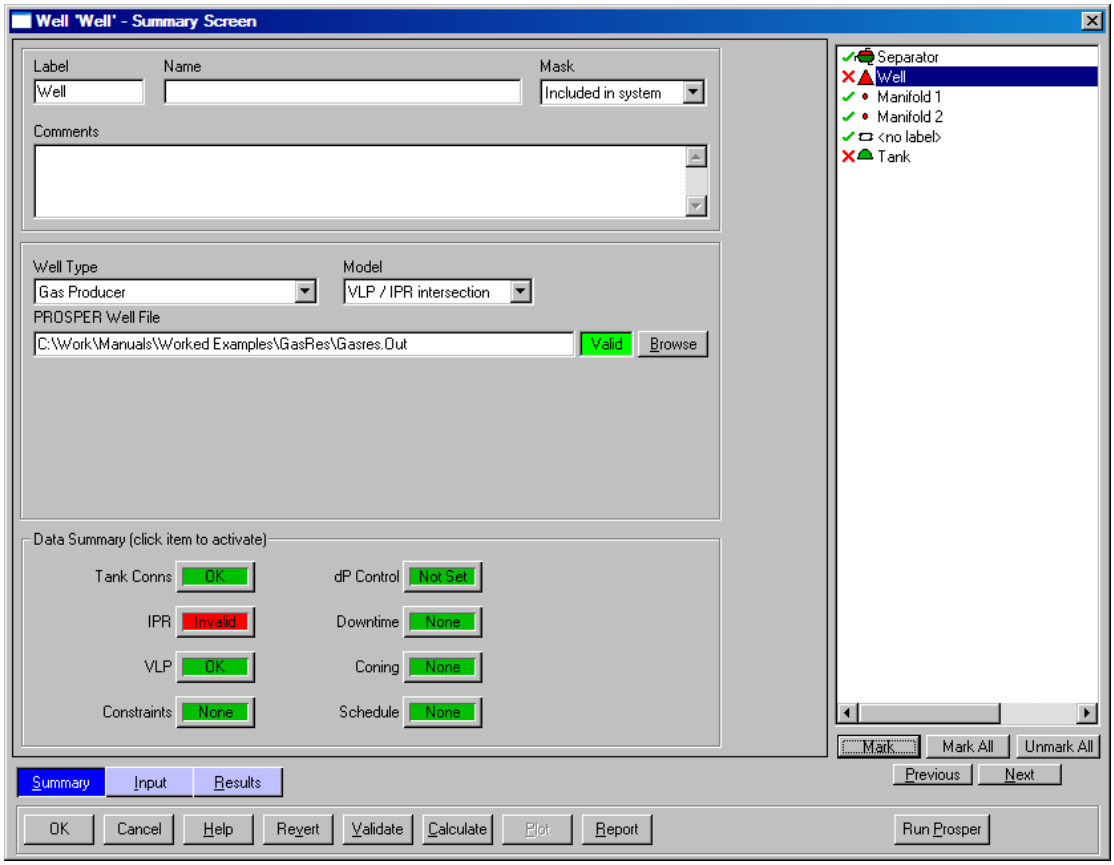


Figure 8: VLP in well screen showing OK

The inflow performance relationship (IPR) of the well has been described in the **PROSPER** well model. We need to transfer the IPR from **PROSPER** to **GAP**. For gas wells, while importing the IPR from **PROSPER** to **GAP**, **GAP** will take three points from the **PROSPER** IPR, and fit the three points with either Forcheimer or C & n IPR method (Defined by user in the IPR screen of the well in **GAP**).

In **GAP**, when selecting **Generate/Transfer IPRs From PROSPER** means open the **PROSPER** file, read three points from **PROSPER** IPR, and fit the points with the selected IPR method in **GAP**.

To transfer the IPR for this well, click on **| Generate | Transfer well IPRs from PROSPER** in the main **GAP** window.

You will see a screen as below:

GENERATE error
All
Select
Cancel
Help
No wells have been selected !
Press the <ALL> button to select all wells
and continue with Generate.
Press the <SELECT> button to highlight the
SELECT icon. You will then be able to select
individual wells to include in the generate
list and then re-start the Generate process

Figure 9: Generate error message

This is because we have not select any well yet. Click on | All to select all the valid wells in the model (in this case only one).

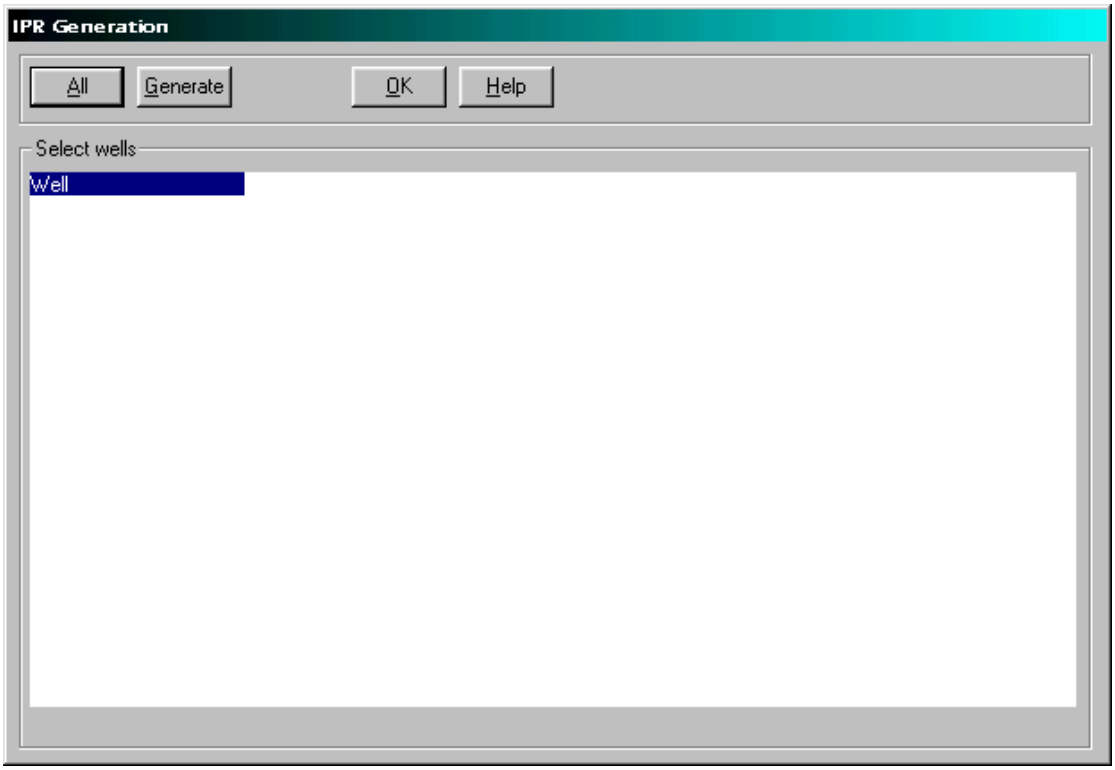


Figure 10: Select wells message

The screen above shows you the selected wells. Click on | Generate to proceed.

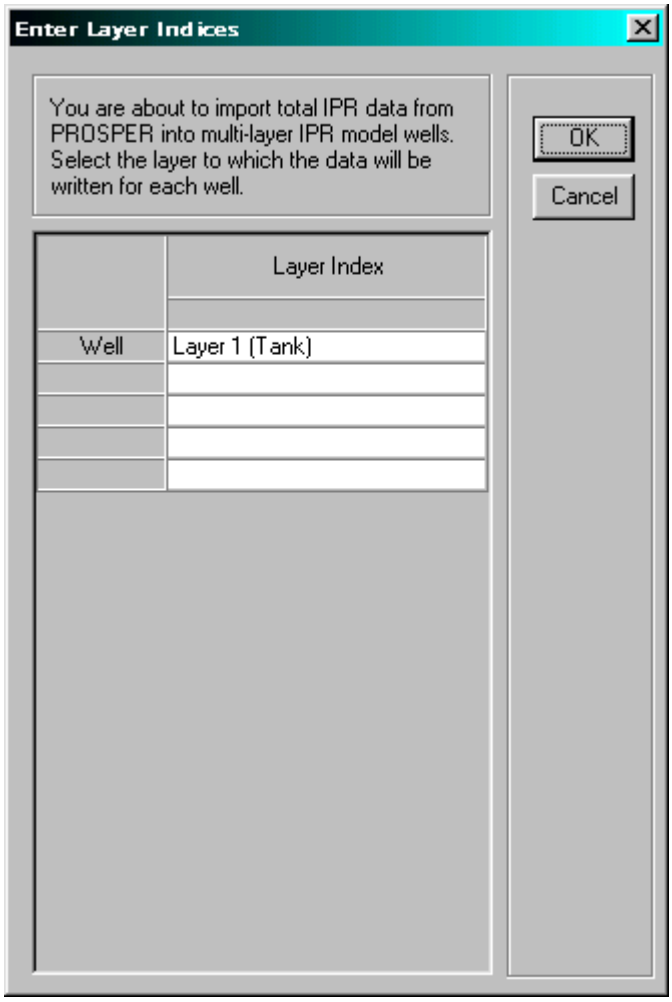

Enter Layer Indices
You are about to import total IPR data from PROSPER into multi-layer IPR model wells. Select the layer to which the data will be written for each well.
OK
Cancel
Layer Index
Well
Layer 1 (Tank)

Figure 11: Select layer message

In **GAP**, you can model multilayer well. Each layer can have their own IPR. In this screen, you are going to tell **GAP**, about the IPR that it is about to read, belongs to which layer. If you have a single layer well, just leave the layer index as it is (layer 1). Click | OK to continue.

The IPR generation will begin and when it finishes, you will see the message:

Figure 12: IPR generation finish message

Click | OK to go back to the main screen. Double-click on the Well icon to bring up the well summary screen. Notice that the colour of the box next to the word 'IPR' is still red. This indicates that although the IPR generation has been completed, the Fractional Flow relative permeability set is still invalid.

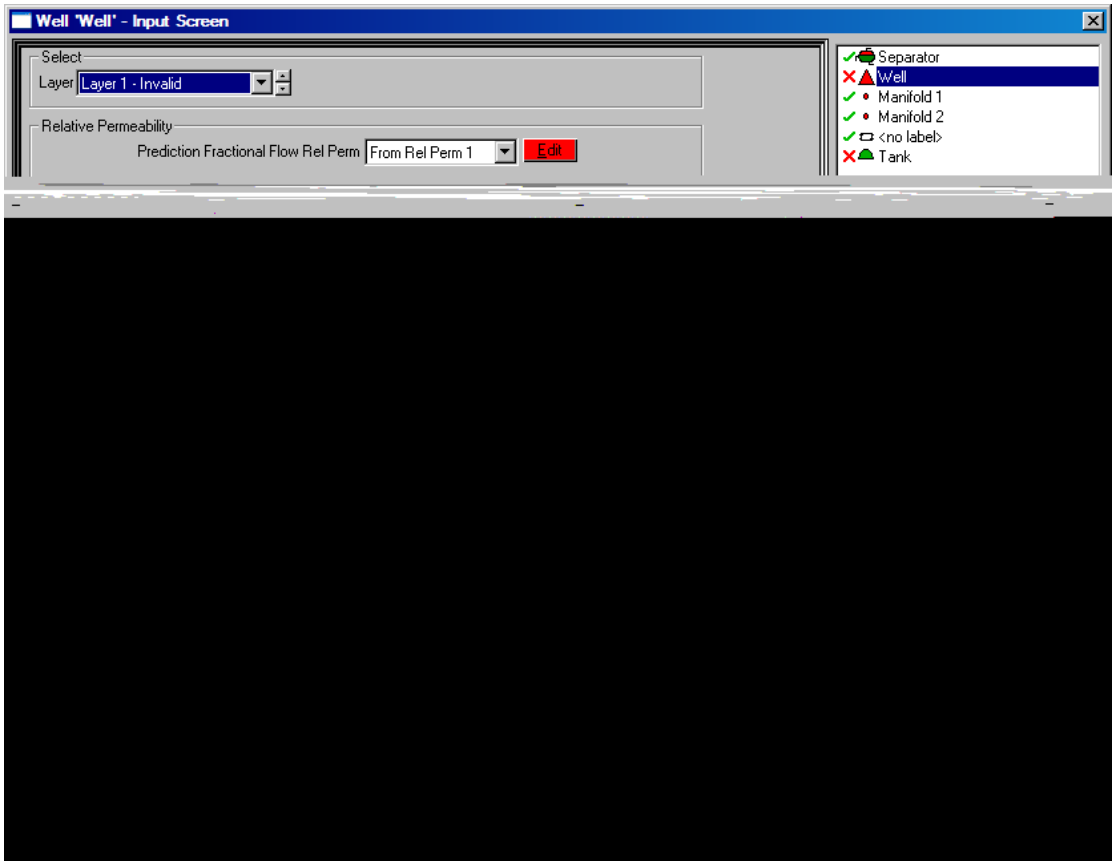
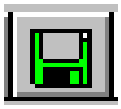


Figure 13: Relative Permeability screen

Click on the drop down menu and select the option “From Tank Model” in order to validate it.

Now save the ***GAP*** file by clicking on  and selecting **Yes** to the overwrite confirmation.

2.1.6 STEP 6 : Solve the GAP Network

This section describes the solving of the Network by the allocation of a separator pressure from which an unconstrained flow can be calculated. This is a precursor to the material balance calculation in which the reservoir pressure reduces as the reservoir fluid is produced.

Double-click the left-hand mouse button within the Well on the main **GAP** display area. Notice that all of the Data Summary flags are green and the Well has a green tick next to it in the list of components on the right side of the Equipment Data Entry screen. If this is not the case, then the VLP and IPR have not been calculated correctly and STEP 5 should be repeated carefully.

Before the Network solver can be performed, the pipe must be defined. Double click the left-hand mouse button over the pipe on the main window and select **Input** at the bottom of the screen, followed by the **Description** tab, leaving the default **Environment** properties. Enter the following pipe data:

Length = 10000 ft
TVD downstream = 0 ft
TVD upstream = 0 ft
Inside diameter = 6 ins
Roughness = 0.0006 ins

Select **OK** to return to the main screen.

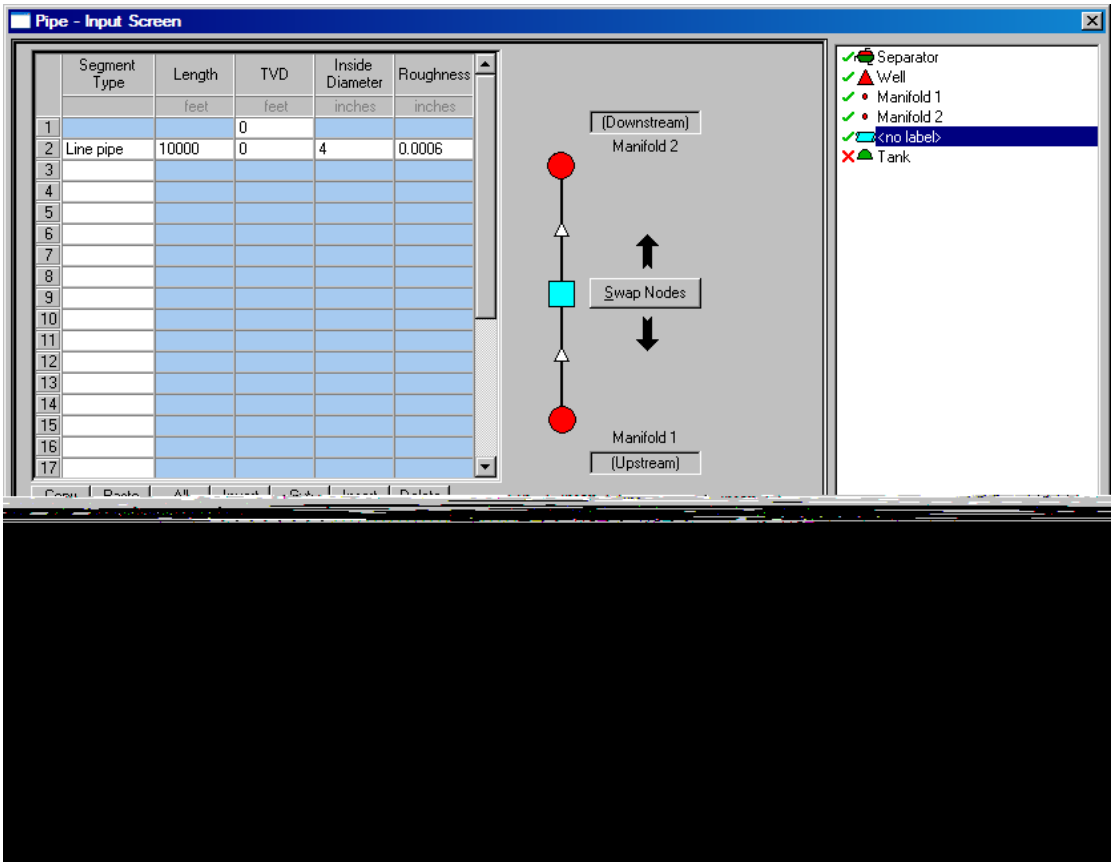


Figure 14: Pipe Data Input

Perform the **Solve Network** from the main menu and put **Pressure 1** Separator Pressue at 1300 psig. Select **Next** | **Calculate**, when the calculation is finished select **Main**. Provided that the pipe line is not a bottle necked the pipe icon will stay blue. If there is a bottle neck the icon would turn red.

The results can be seen by hovering the mouse over each node. The following information will be seen: Pressure; Temp.; Qo; Qg; Qwat; Qginj; and dP for the exit point of that item.

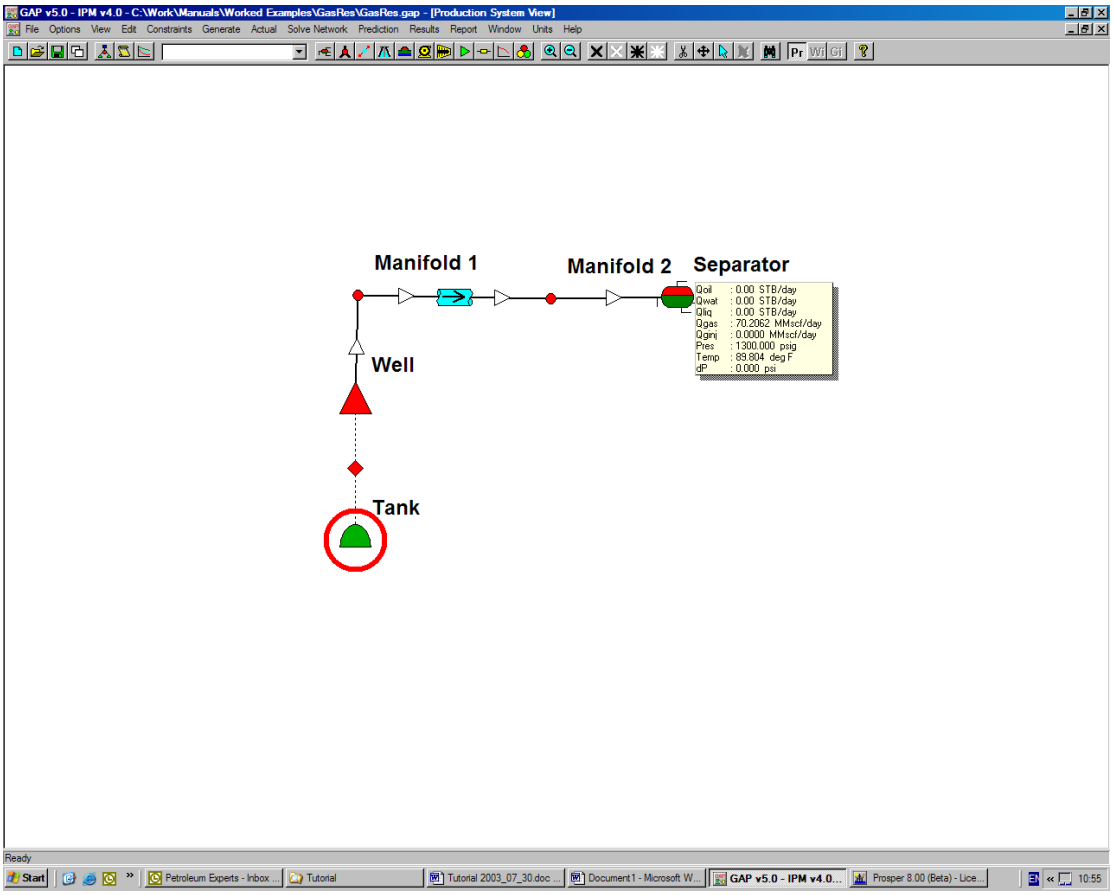


Figure 15: Check solution

If a pressure is allocated to the Separator, then the flow within the network can be calculated by ***GAP*** tracing back through the component PCs from the separator towards the well.

Now the results can be viewed. Select **Results | Detailed | All Items** and note the gas production rate of 70 MMscf/day. Select **OK** to return to the main ***GAP*** window.

Now save the ***GAP*** file by clicking on and selecting Yes to the overwrite confirmation.

2.1.7 STEP 7 : Material Balance Prediction

In this section a tank model is defined using **MBAL**, and a material balance prediction of flow and pressure decline is undertaken.

Go to the MBAL Gas Reservoir Example now – see Section 2.3. The standalone version of **MBAL** must be used to generate the tank model. Double Click on the tank and then select **Run MBAL** in the Summary Screen.

If **MBAL** has been accessed from **GAP**, upon returning to **GAP** from **MBAL**, the path of the **MBAL** file should be displayed in the Tank Summary Screen of **GAP**. However, if you prepare the **MBAL** file by running **MBAL** independently, then you have to specify the file path of the **MBAL** model for **GAP** manually. To do this, double click the left-hand mouse button over the Tank within the main display, and select **Browse** to locate the **MBAL** file (GASRES.MBI). Notice that the Tank component now has green tick beside its name in the right side of the Equipment Data Entry screen.

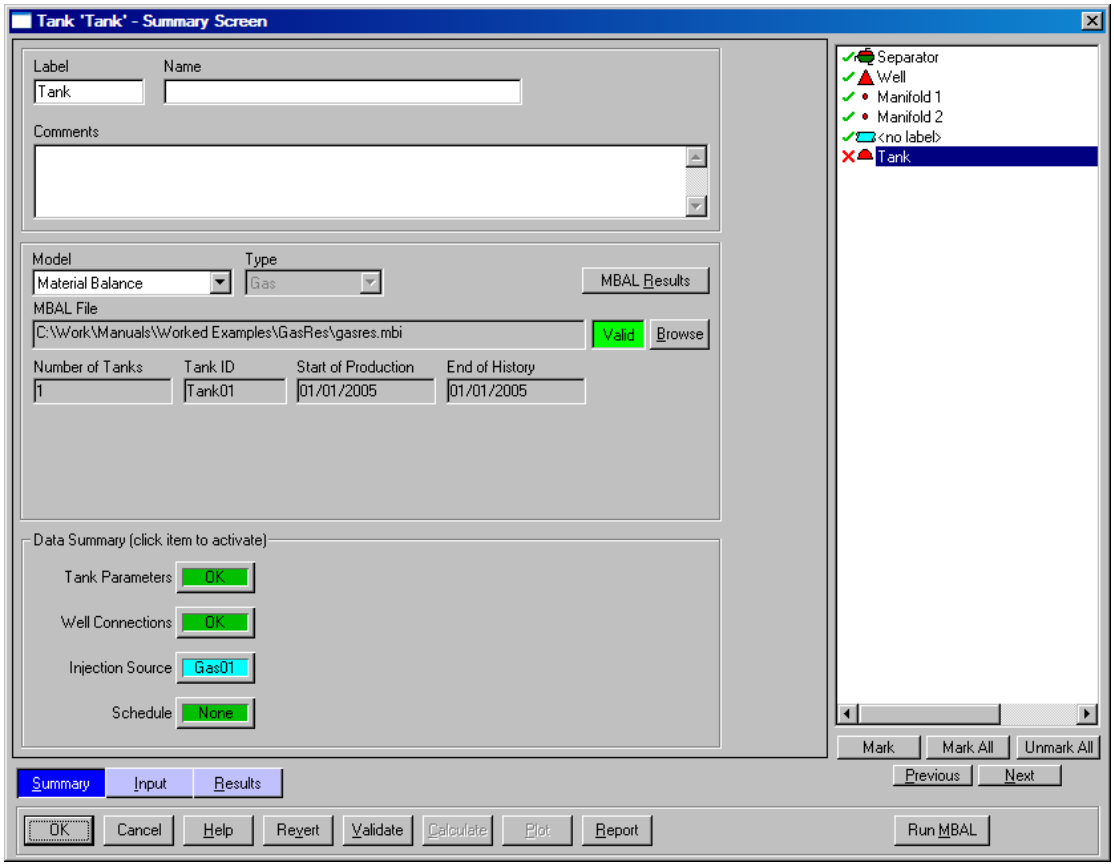


Figure 16: Tank summary screen

The material balance tank model is now in place and a prediction can be performed. A straightforward prediction will be run first, with no constraints or events occurring during the production. This is essentially the same as the Solve Network calculation performed previously, except that a material balance calculation is performed after each time step to update the reservoir pressure and **PVT** properties.

Select **Prediction | Run Prediction** and set the following time control data.

- Start Date 01/01/2005

- End Date 01/01/2020
- Step Size 1 Year(s)

Select **Next** | **Next** and allocate a Separator pressure of 1300 psig. Select **Next | Calculate** and allow the Solve Network cycle to be performed for each of the 15 time steps requested.

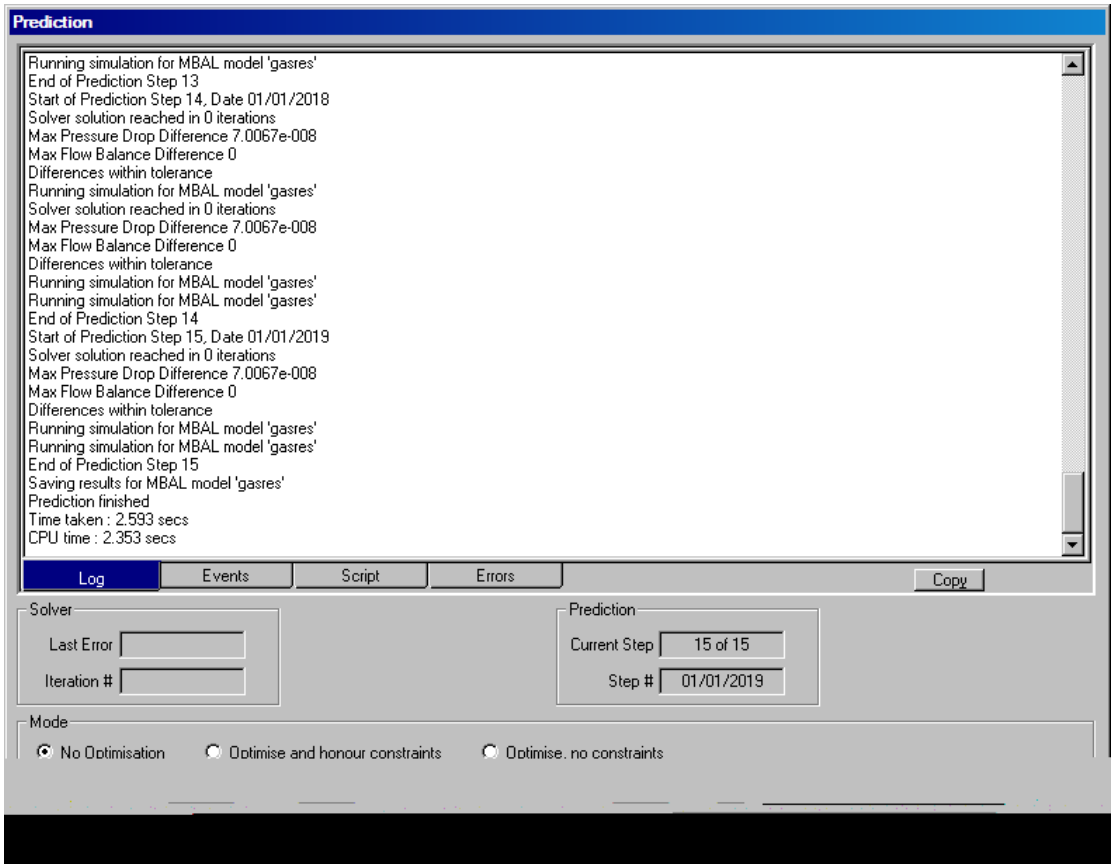


Figure 17: Calculation screen

When the run is complete select **Back | Back**.

The results from the material balance prediction can be viewed by selecting **Plot Nodes**, and highlighting the Separator, Manifold 1 and 2 and Well nodes from the resulting list. Since the components are all in series, the flow parameters should be identical for each node and have overlying curves.

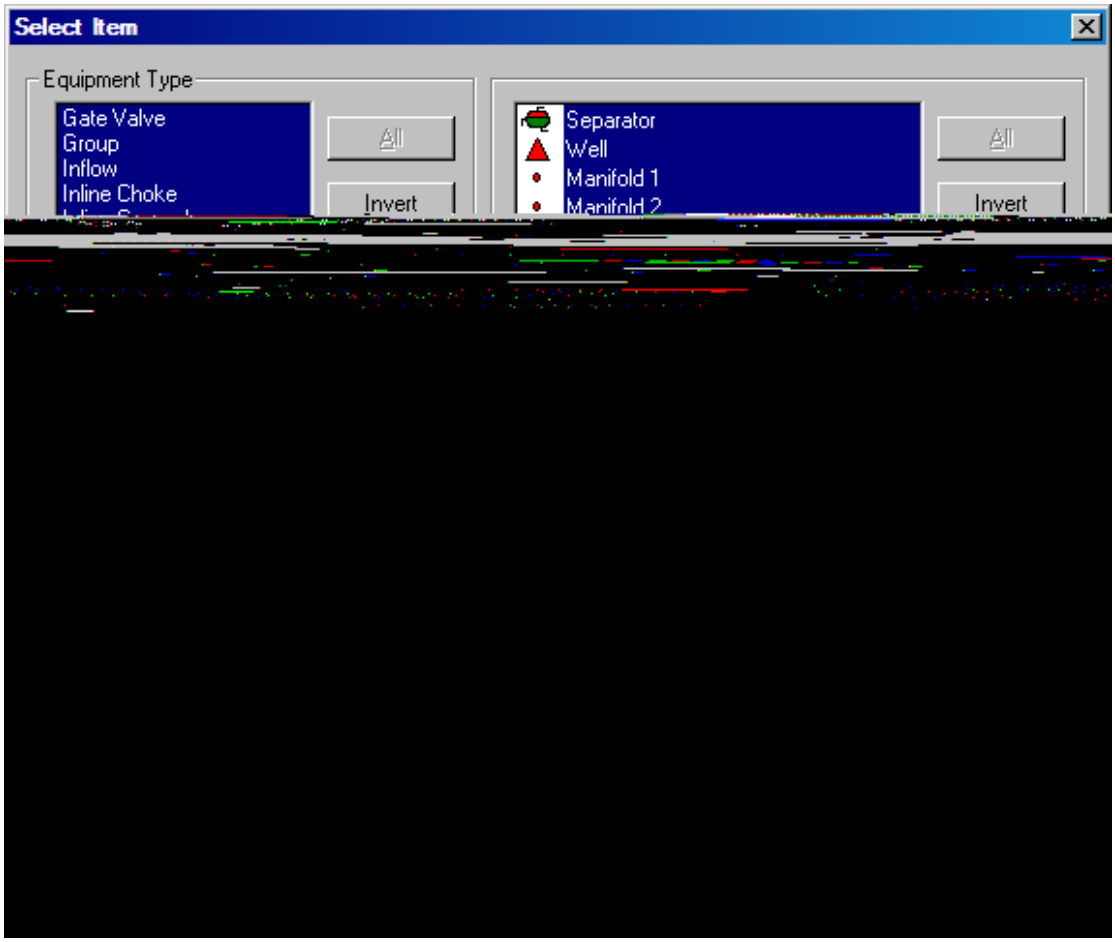


Figure 18: Select nodes to plot

Click on **Plot** and a plot window will appear. Select **Variables** and look at the plot for **Gas rate** by highlighting it and selecting **OK**. Plot the **Water rate**, **Reservoir pressure** and **Cum Gas Production** graphs.

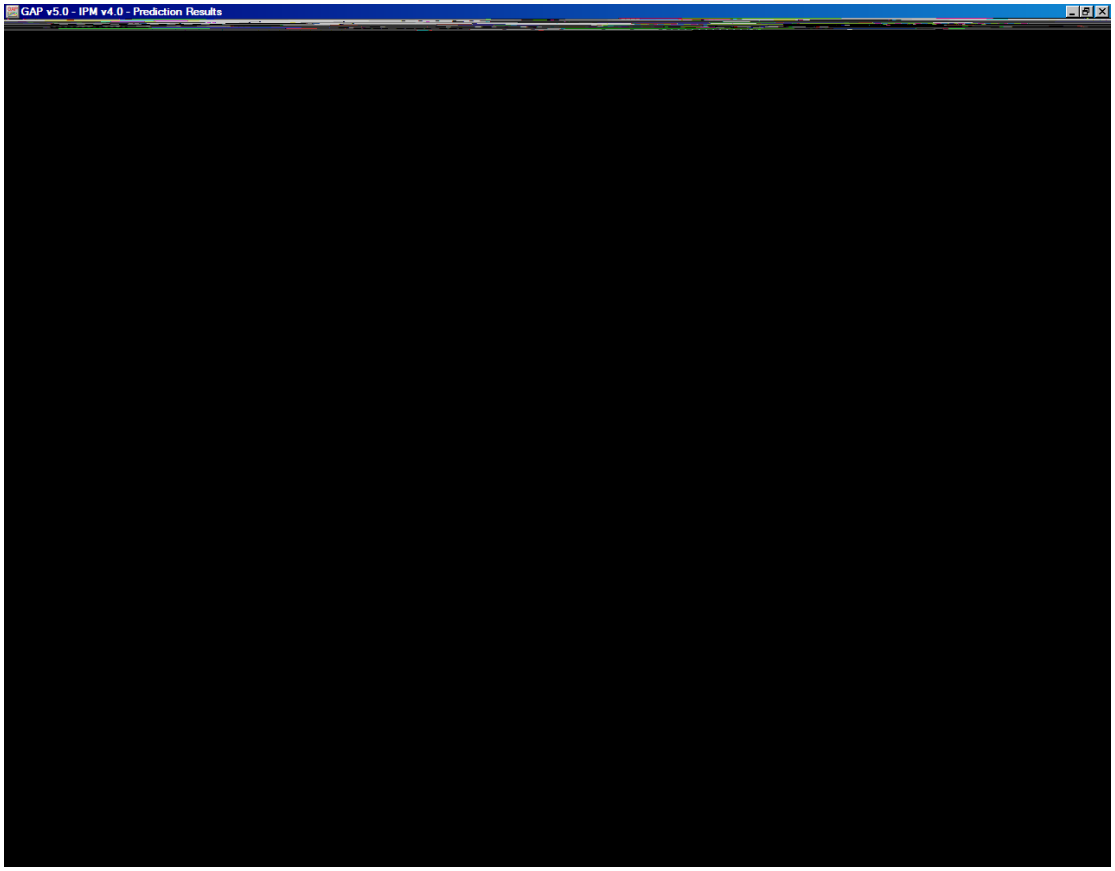


Figure 19: Results – Gas rates

The initial peak gas rate should be 70 MMscf/day, and the peak water rate should be 43 STB/day. This water is the vaporised and connate water released as the reservoir depressurises and the water and formation rocks contract. Select **Main** to return the main **GAP** window.

No constraints have been entered for this system, and it is recommended that none are entered until the potential of the system has been established. At this point the user should consider design options, potential problems and possibly sensitivity analysis.

Now save the **GAP** file by clicking on and selecting **Yes** to the overwrite confirmation.

2.1.8 STEP 8 : Constraints

In this section a constraint will be applied to the maximum flow rate that can be passed through the separator. One of the wells will initially have to be choked back to satisfy the separator constraint.

Select the well icon and add a new well next to the current well.

The already defined well properties (VLPs, IPR, **PVT** etc) can be copied to the new well by holding the **Ctrl** key down while selecting the first well with the left mouse button, and dragging the mouse over the new well.

Add a link between the new well and the Manifold 2 using the link icon, and then deselect the link icon.

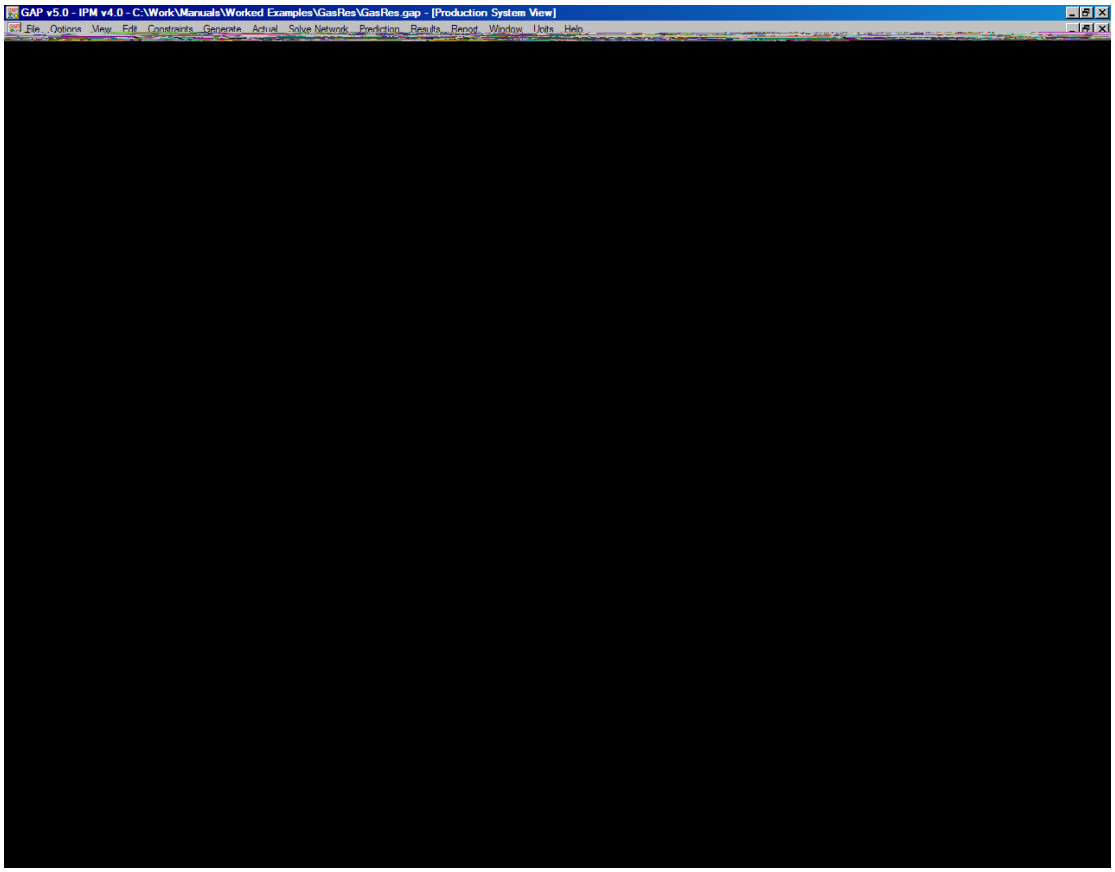

GAP v5.0 - IPM v4.0 - C:\Work\Manuals\Worked Examples\GasRes\GasRes.gap - [Production System View]
File Options View Edit Constraints Generate Actual Solve Network Prediction Results Report Window Units Help

Figure 20: Adding a second well

Enter the Summary Data Entry screen for the second well by double-clicking on the icon with the left-hand mouse button. Change its label to Well 2 in the top left of the screen, and then click on the green area next to **dP Control** in the lower part of the screen. These buttons are accelerators to different screens of equipment input data. Set the "**dP Control**" box to **Yes** and the Delta P Choice to **Calculated**. This will simulate the presence of a well head choke that allows ***GAP*** to reduce the flow from the well and meet any constraints imposed on the system.

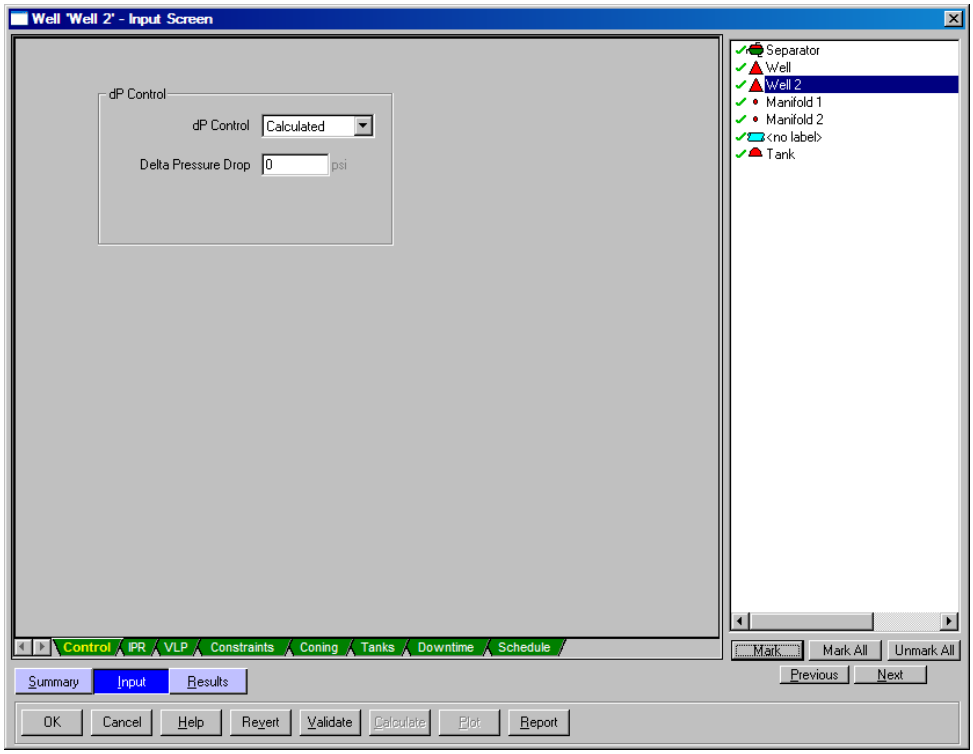


Figure 21: Setting the well to controllable choke

Select **OK**. The potentially choked (controllable) well will have a ring around it.

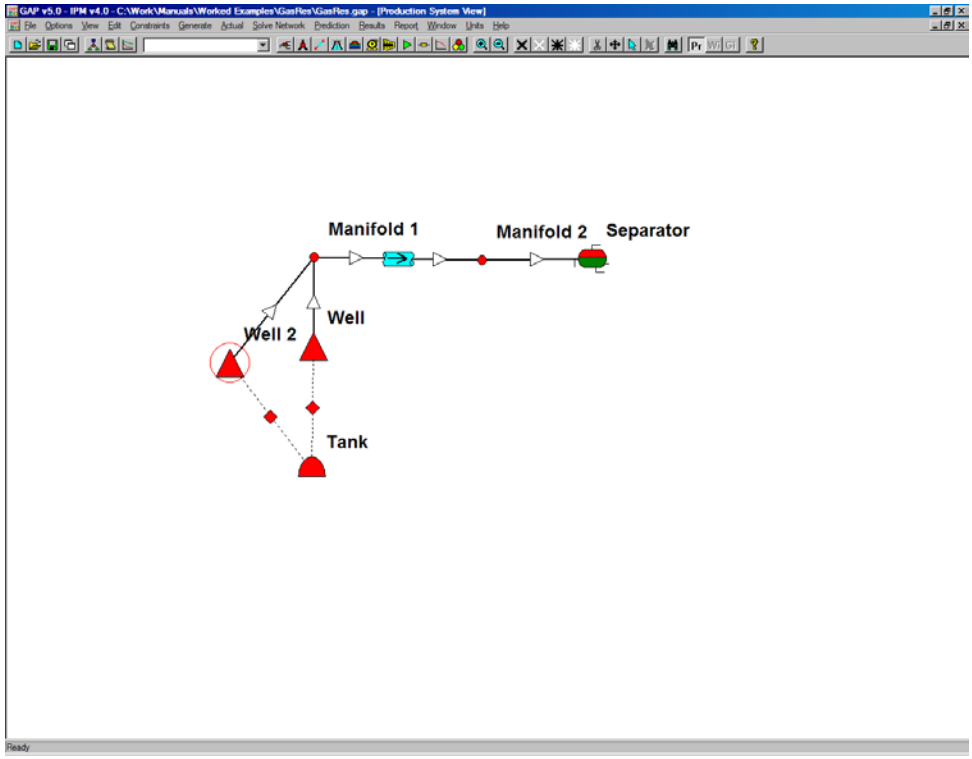


Figure 22: Controllable well has a thin red circle around it

Enter the Separator data entry screen by double-clicking the left-hand mouse button over the separator icon. Navigate to the Constraints data entry by clicking on the Constraints accelerator in the lower half of the Equipment Data Entry screen. Enter a Max gas production of 100 MMscf/day, and then select **OK**.

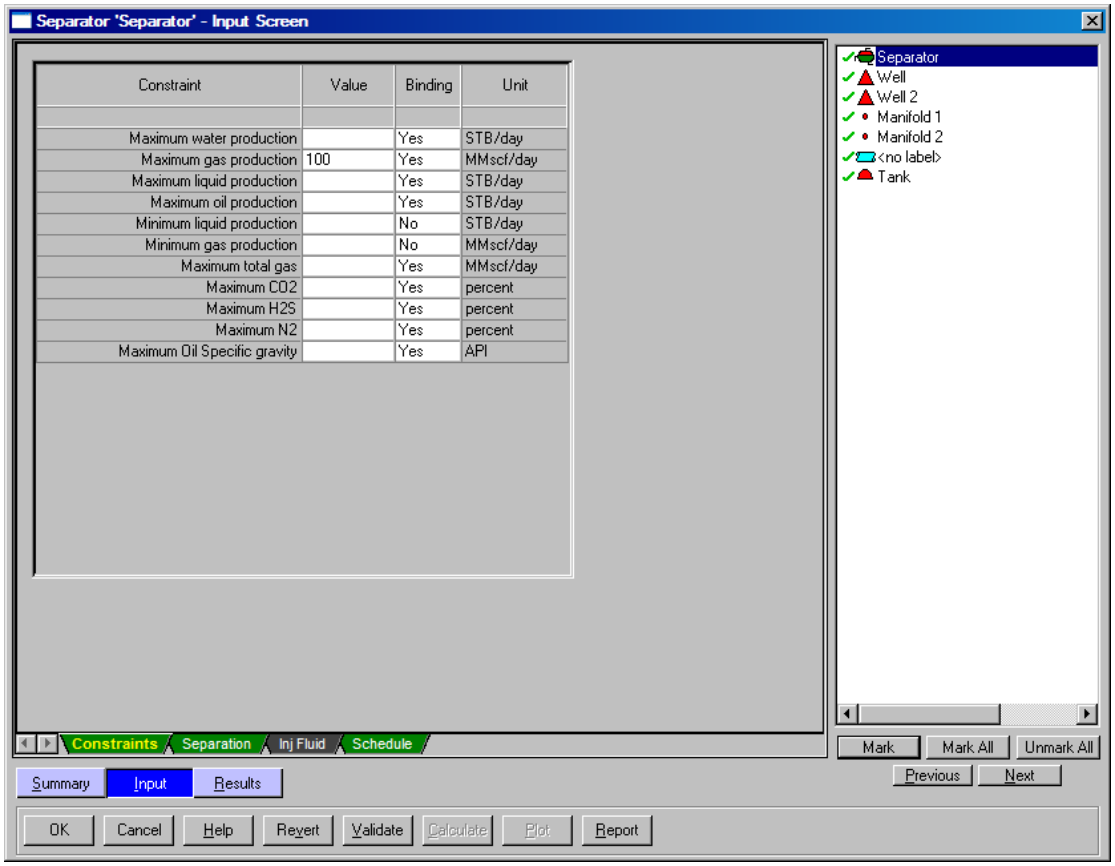


Figure 23: Setting constraint at separator

The separator constraint is shown on the display as two inward pointing arrows, as shown in the figure below.

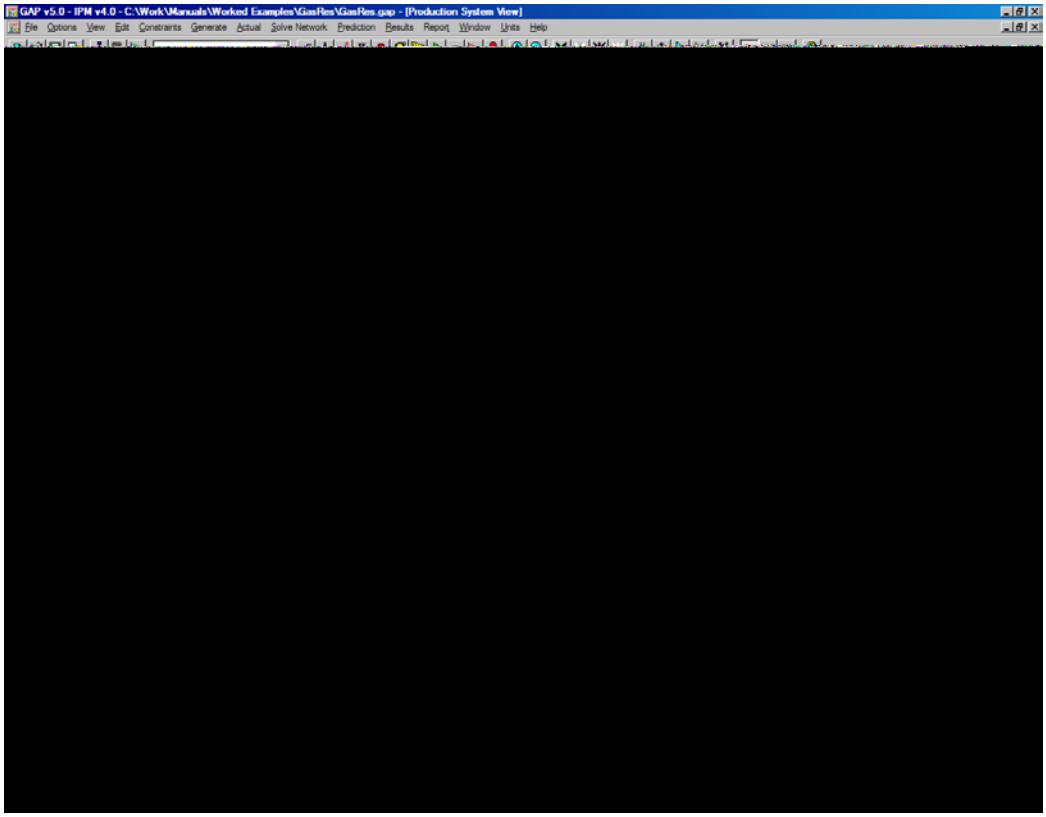


Figure 24: Schematic Diagram with Controllable Well and Constrained Separator

Select **Solve Network | Next** click on the **Optimise and Honour Constraints** option:

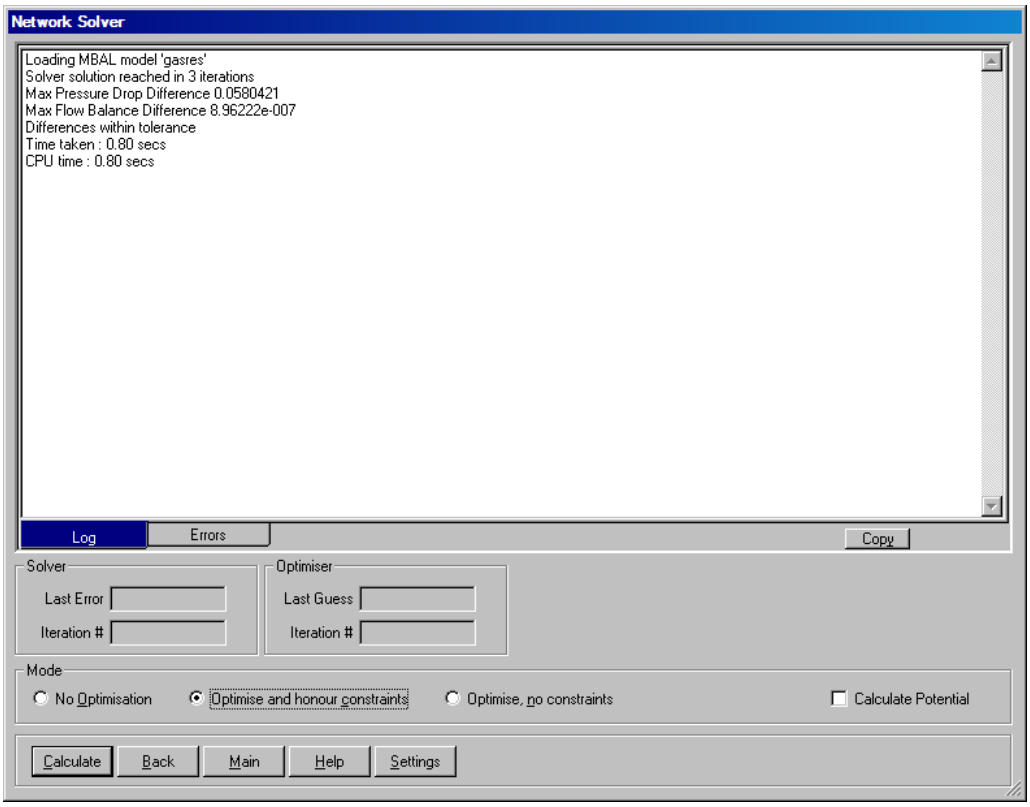


Figure 25: Calculation screen showing Optimise checkbox

and **Calculate** to solve the system with constraint, then **Main** when the calculation has finished. As you have two wells and one is selected with dP control, using optimise the solver will control Well 2 to achieve the constraint set at the Separator. Go to **Results | Detailed | All Wells**. The Gas production for the two wells can then be noted. Use **Next** to move to Well 2 and not that the production has been choked back to 33 MMscf/day to achieve to constraint at separator.

Notice that the pipe icon has changed colour from blue to red. This indicates that this pipeline is bottlenecking the system.

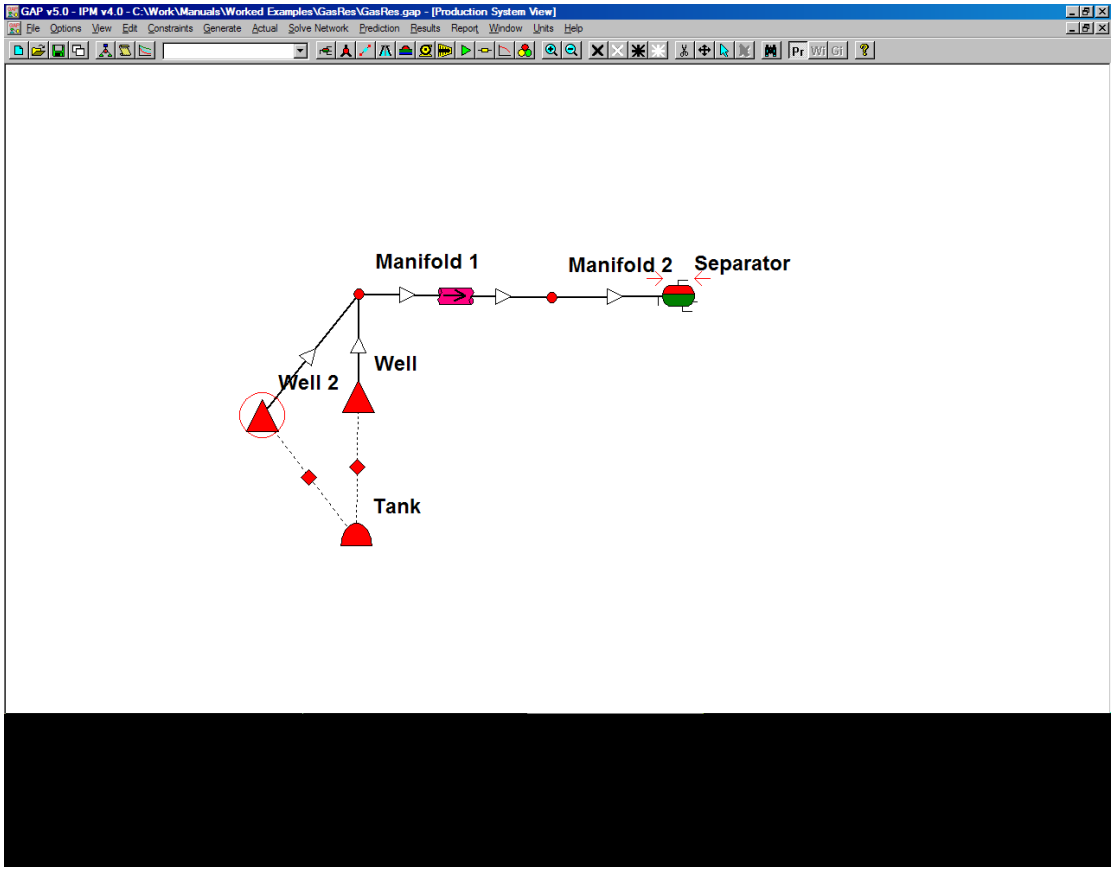

GAP v5.0 - IPM v4.0 - C:\Work\Manuals\Worked Examples\GasRes\GasRes.gap - [Production System View]
File Options View Edit Constraints Generate Actual Solve Network Prediction Results Report Window Units Help
Manifold 1
Manifold 2
Separator
Well
Well 2
Tank

Figure 26: Bottle-neck pipeline

Double click on the pipe and select **Results | Network Solver** tab screen and note that the **Bottle Neck flag** shows **Choked.** From this we see that the combined flow from the two wells can be greater, but the pipe between the Manifold 2 and Manifold 1 is bottlenecking the system.

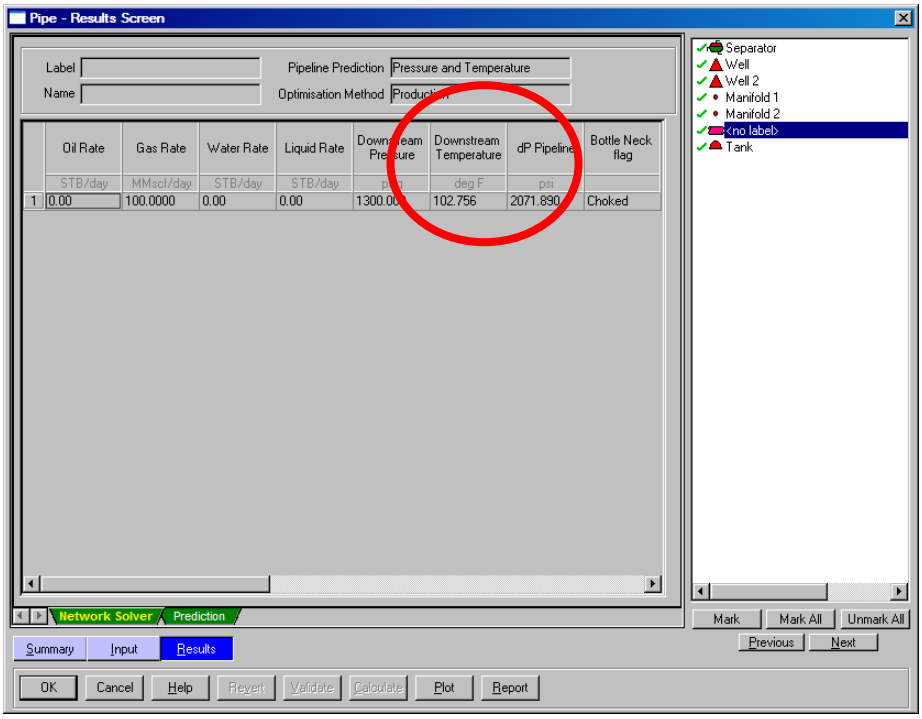


Figure 27: Bottle neck flag

If a prediction is now done (selecting to honour the constraints), then Well 2 will be choked back as long as the potential of the system is greater than the constraint set:

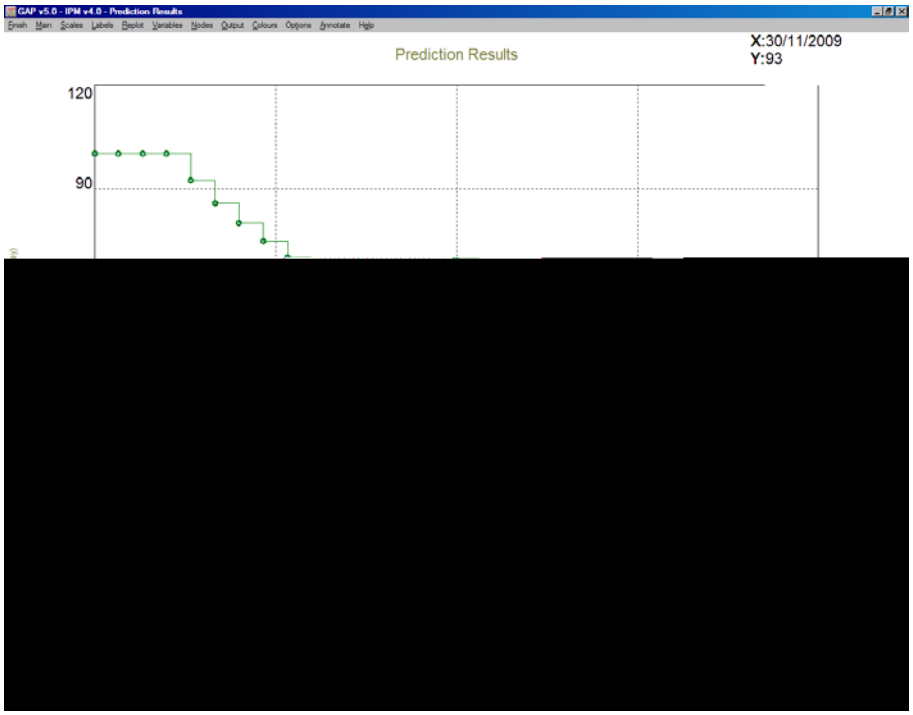


Figure 28: Well results

Save the ***GAP*** file using and select **Yes** to overwrite the current file.

2.2 PROSPER Gas Well Example

This tutorial example is designed to provide a step-by-step introduction to the **PROSPER** program. The emphasis is on the data entry required to model a dry gas producing well for inclusion into a **GAP** model. See the **GAP** Gas Network Example for further details. Since it is hoped that this example will be used as a phase in the **GAP** Gas Network Example, it is anticipated that **PROSPER** will have been loaded from within **GAP**. However if that is not the case, this example can be run using the standalone version of **PROSPER**.

PROSPER is a single well characterisation program. Its output is principally Inflow Performance Relations (IPRs) and Vertical Lift Performances (VLPs). These relations respectively describe the inflow to the well sandface from the reservoir and the outflow from the well sandface to a manifold (or well head) at the top of the well. These pressure and flow correlations are heavily reliant on the **PVT** (Pressure, Volume, and Temperature) characteristics of the produced fluid. Using Inflow and Outflow, we know the behaviour of the well in terms of the flow rates vs. bottom hole pressures for a given mean reservoir pressure.

In addition **PROSPER** has tools to match known correlations to observed production history and perform detailed sensitivity analyses.

2.2.1 STEP 1 : Initialise PROSPER

If **PROSPER** has not been started from with **GAP**, then start the **PROSPER** program by running **PROSPER**.EXE, which can be found in the *Petroleum Experts* directory (default C:\Program Files\Petroleum Experts\IPM 4.0). See the **PROSPER** manual for more details on how to start **PROSPER**.

Check that the current version of **PROSPER** has been loaded. The version of **PROSPER** being used can be seen in the title bar.

The command options (**File**, **Options** etc.) at the top of the **PROSPER** window are laid out in a logical order (left to right) that reflects the order in which operations will usually be performed.

Select **File | New** to start a new file if required. If this option is not available, then **PROSPER** has already started a new file.

Note that files saved with this version of **PROSPER** *will not* be readable by previous versions. Select **File | Preferences** followed by the **File** tab. It is recommended that the **Default Data Directory** field is set (using the **Browse** button) to point to a directory that is exclusively used to store data files created with the current software version.

Now select the **Units** tab. It is important to ensure that consistent units are used throughout, particularly when data generated by **PROSPER** may be incorporated into an **MBAL** or **GAP** model. Oilfield units will be used for this example. Ensure that **Input Units** and **Output Units** box have **Oilfield** selected. Select **Done** to return to the main **PROSPER** window.

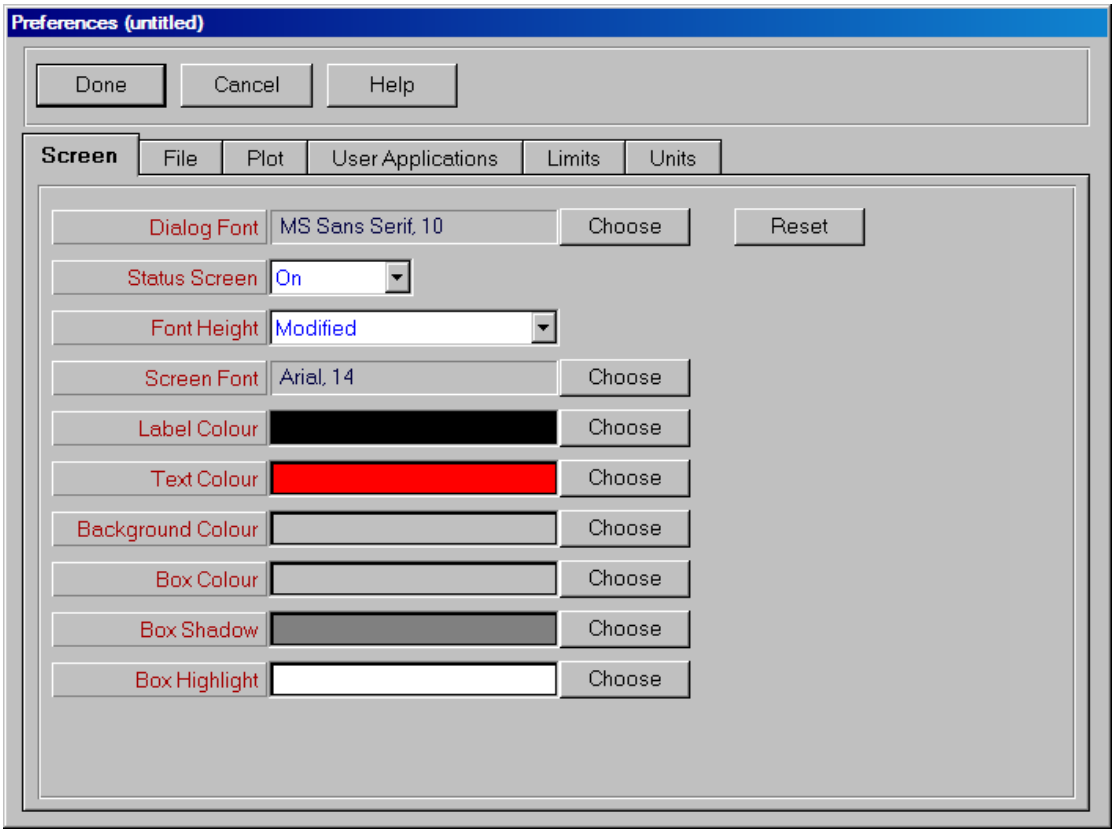


Figure 29: Preferences screen

2.2.2 STEP 2 : Initialise *PROSPER* Method Options

In this section the type of well and reservoir fluid that ***PROSPER*** will use are defined. Their detailed specification will be entered later.

This example has a dry gas producing well. Select **Options | Options** to display the System Summary screen. This screen is primarily used so that ***PROSPER*** can provide only the relevant screens as the model is constructed. Set the options shown below and click **Done**.

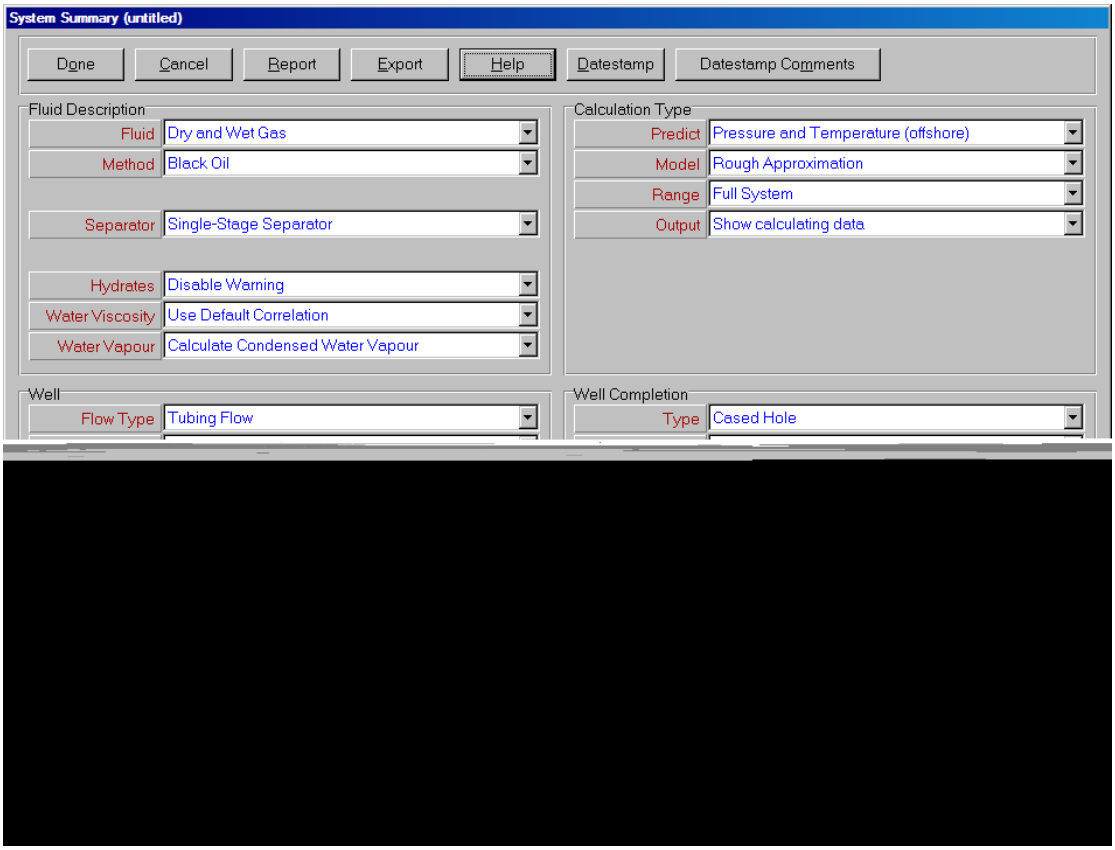


Figure 30: Completed System Summary Screen

2.2.3 STEP 3 : Initialise PVT Data

This simple example will use an unmatched Black Oil **PVT** to characterise the reservoir fluid. Select **PVT | Input Data** to enter the **PVT** data. Notice the options to match correlations to data, or to use lookup tables of **PVT** data. Enter the following data and select **Done**.

Gas gravity	0.59
Separator pressure	100 psig
Condensate to Gas Ratio	0 STB/MMscf
Condensate gravity	50 API
Water to Gas ratio	0 STB/MMscf
Water salinity	10000 ppm
Mole Percent H2S	0 %
Mole Percent CO2	0 %
Mole Percent N2	0 %
Reservoir Pressure	11500 psig
Reservoir Temperature	230 deg F

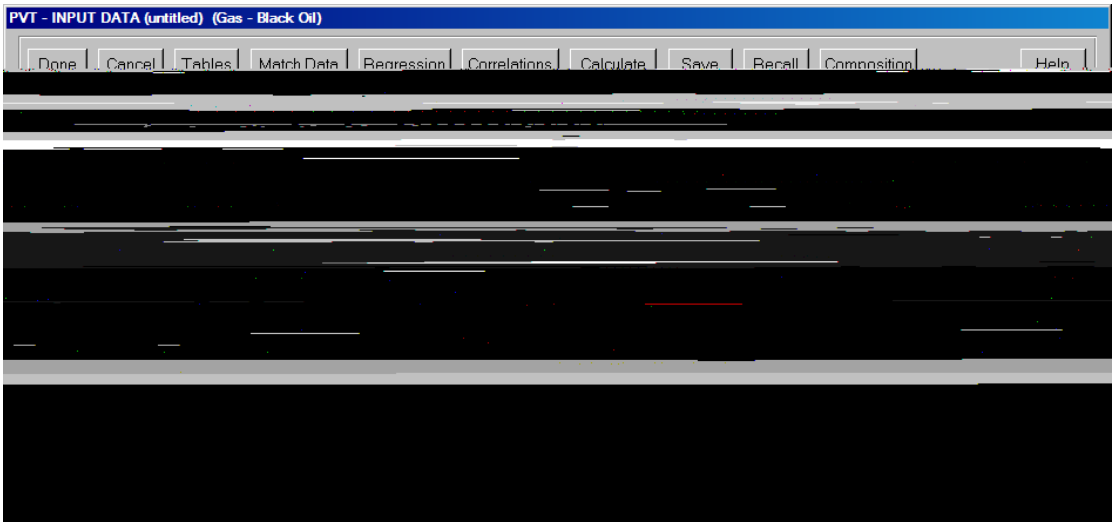


Figure 31: **PVT** Data Screen

The condensate gravity of 50 API will not be used for a dry gas, however a value greater than 5 is required by default. See the ***PROSPER*** manual on details of how to change unit range defaults.

2.2.4 STEP 4 : Initialise Well Inflow and Equipment

This step defines the properties of the reservoir and well that will determine the flow rate of the produced fluid for a given reservoir pressure and well head pressure.

Select **System | Equipment (Tubing etc)** to input the well properties. Select **All**, and then **Edit**. Enter the following deviation survey data describing a vertical well profile down to a depth of 17350 ft. Click **Done** when the deviation survey data has been entered.

Measured Depth (ft)	True Vertical Depth (ft)
0	0
17350	17350

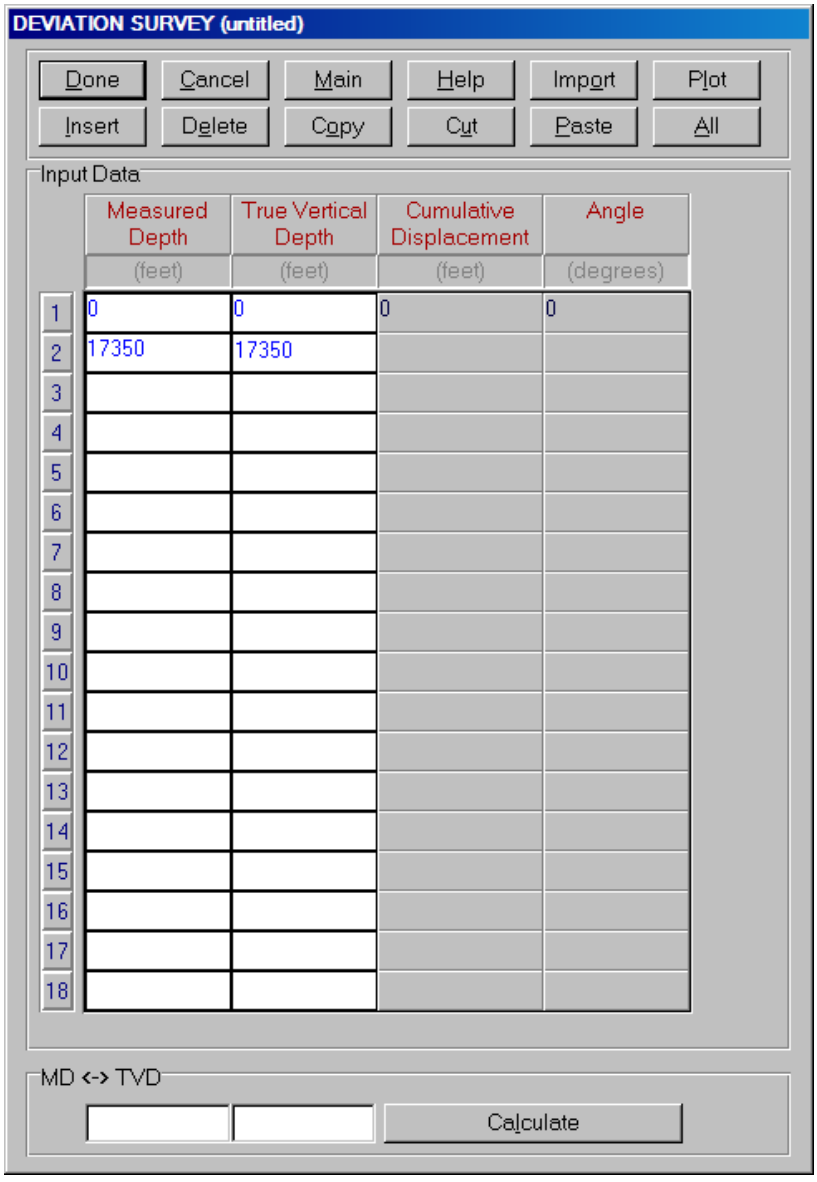


Figure 32: Deviation Survey

No surface equipment will be entered for this simple model. Note that all equipment between the well head and manifold defined in ***GAP*** would in general have to be entered here. Select **Cancel**.

Enter the following tubing and casing data in the downhole equipment screen, and then click **Done**.

Type	Measured depth (ft)	Inside diameter (in)	Roughness (in)
X'mass tree	0	-	-
Tubing	17250	2.992	0.0006
Casing	17350	6	0.0006

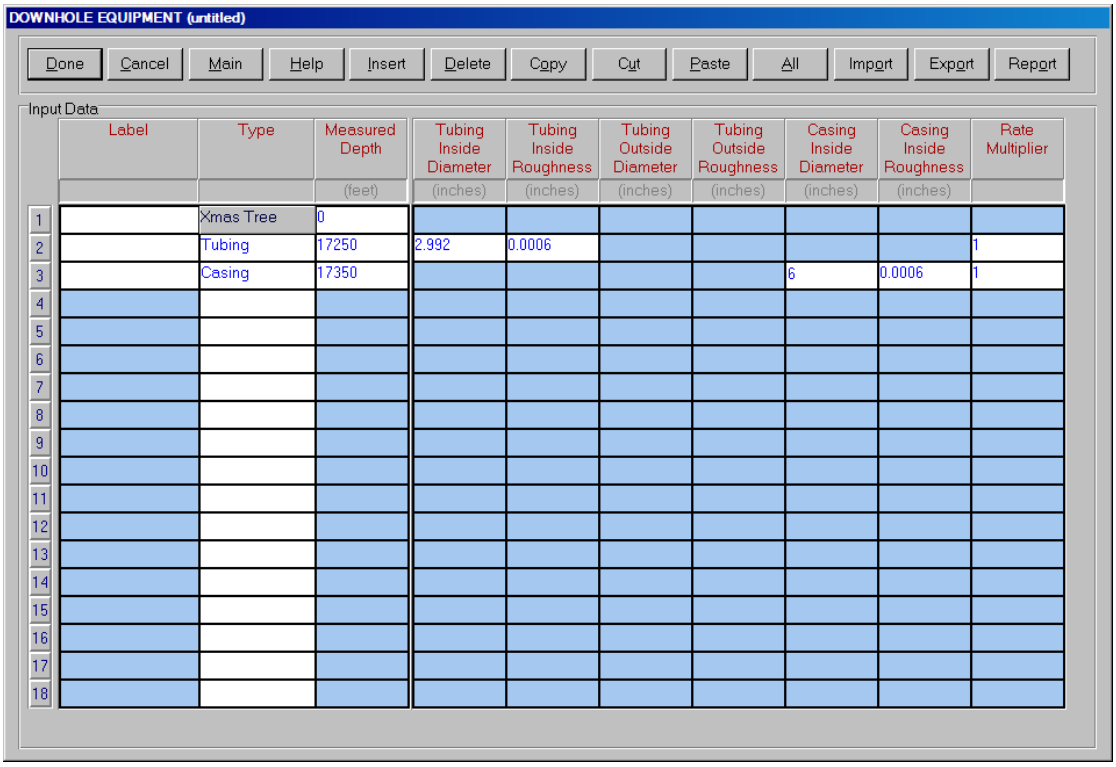


Figure 33: Downhole Equipment

This model is performing a pressure and temperature calculation, therefore the temperature of the surrounding formations and a mean heat transfer coefficient are required. Enter the following linear geothermal gradient and then select **Done**.

Measured Depth (ft)	Formation temperature (°F)
0	60
17350	230

Overall heat transfer coefficient 3 BTU/ft2/F/hr

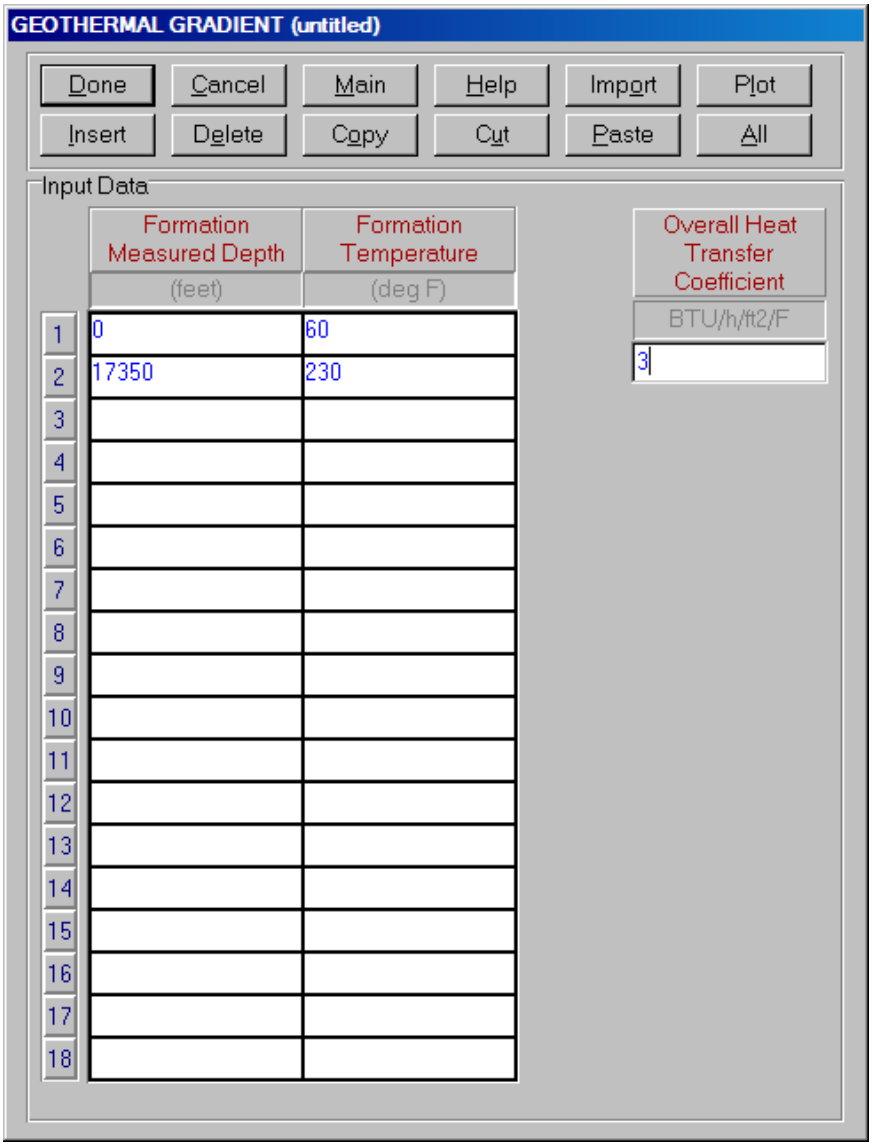


Figure 34: Geothermal Gradient

For Average Heat Capacity, we use the default values. Click on **Done** to accept the values.

We are now back to the main Equipment Entry screen. Select **Summary | Draw Downhole** to view a schematic of the downhole equipment that has been entered. Select **Main** to save the input data and return to the main ***PROSPER*** window.

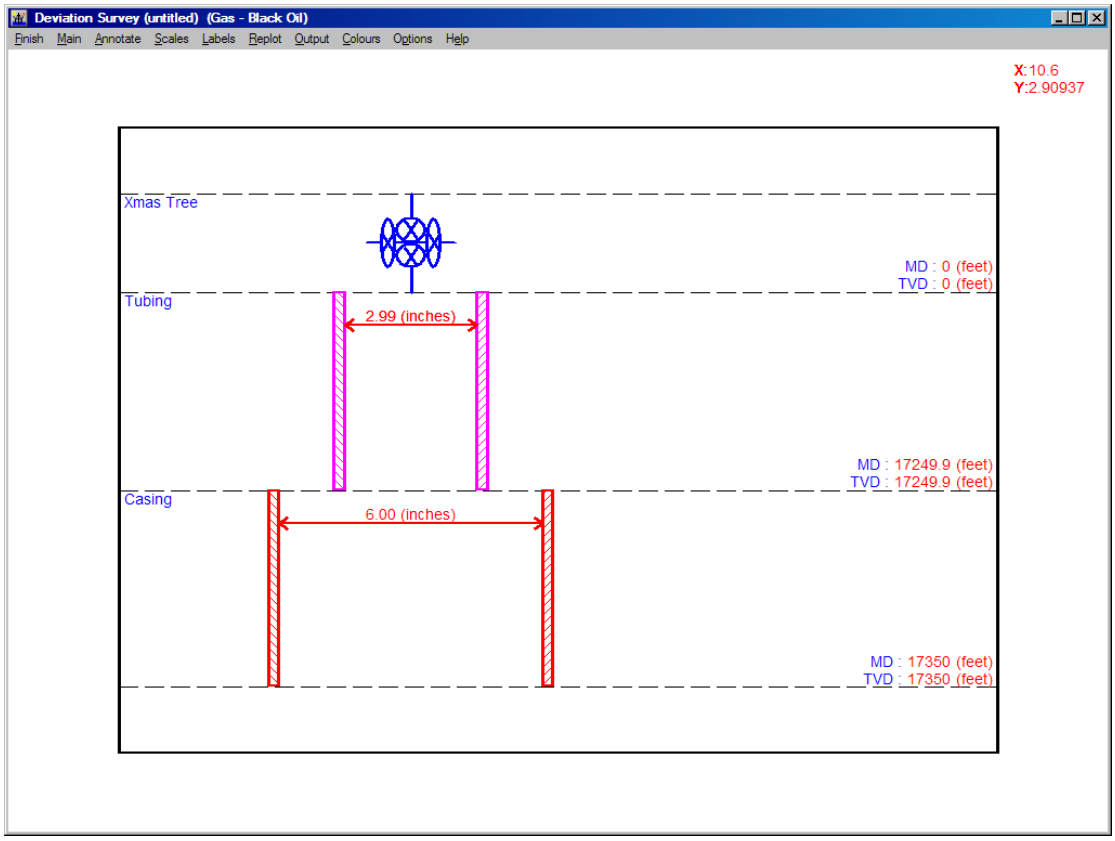


Figure 35: Downhole equipment sketch

The data required to calculate VLPs has been defined, although the VLP correlation function has not yet been entered. Now the reservoir inflow must be characterised by defining an IPR.

In ***PROSPER*** main screen, select **System | Inflow Performance** to open the IPR Input screen. Highlight the **Petroleum Experts** Reservoir Model and **Enter Skin By Hand** for the Mechanical/Geometrical Skin. Set the following data in the lower right of the screen.

- Reservoir Pressure 11500 psig
- Reservoir Temperature 230 degrees F
- Water Gas Ratio 0 STB/MMscf
- Condensate Gas Ratio 0 STB/MMscf

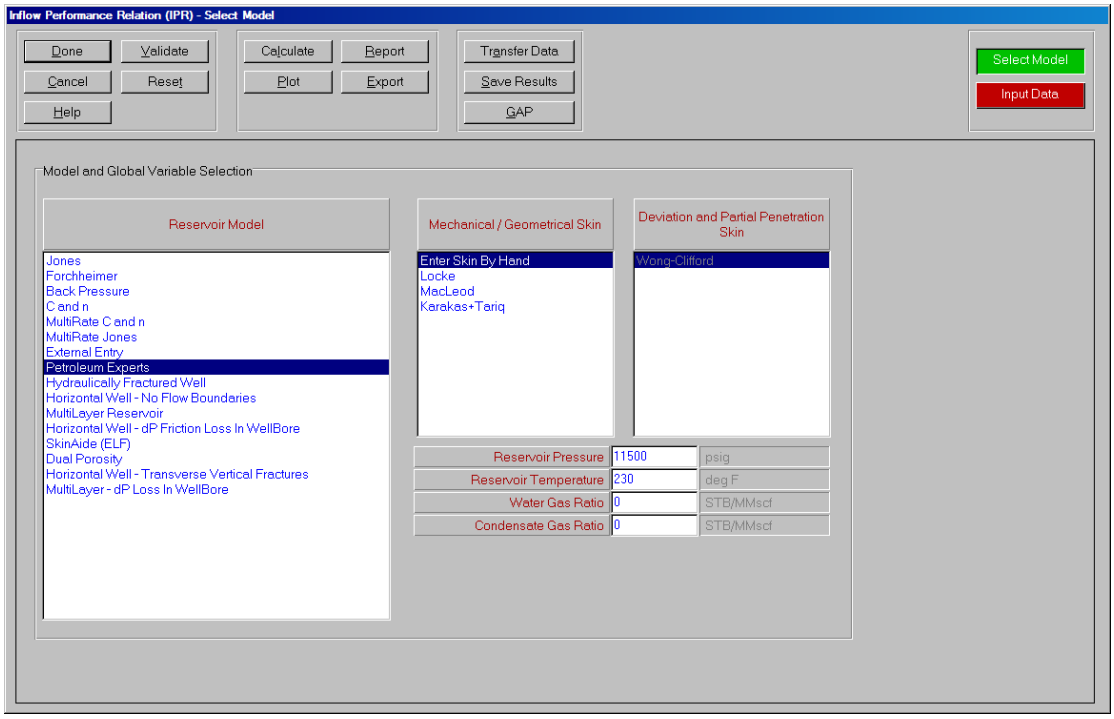


Figure 36: Inflow performance model selection

Select the **Input Data** button at the top right of the screen and enter the following data within the **Reservoir Model** tab.

- Reservoir Permeability 20 md
- Reservoir Thickness 100 feet
- Drainage Area 2500 acres
- Dietz Shape Factor 31.6
- Wellbore Radius 0.354 feet
- Perforation Interval 30 feet
- Time 100 days
- Reservoir Porosity 0.2
- Swc 0.2

Select the **Mech/Geom Skin** tab and enter a value of **2**. Select **Calculate**. An IPR plot showing the inflow to the well as a function of the well's sandface pressure will be shown. An AOF of 143 MMscf/day is shown as the cutoff (maximum) flow.

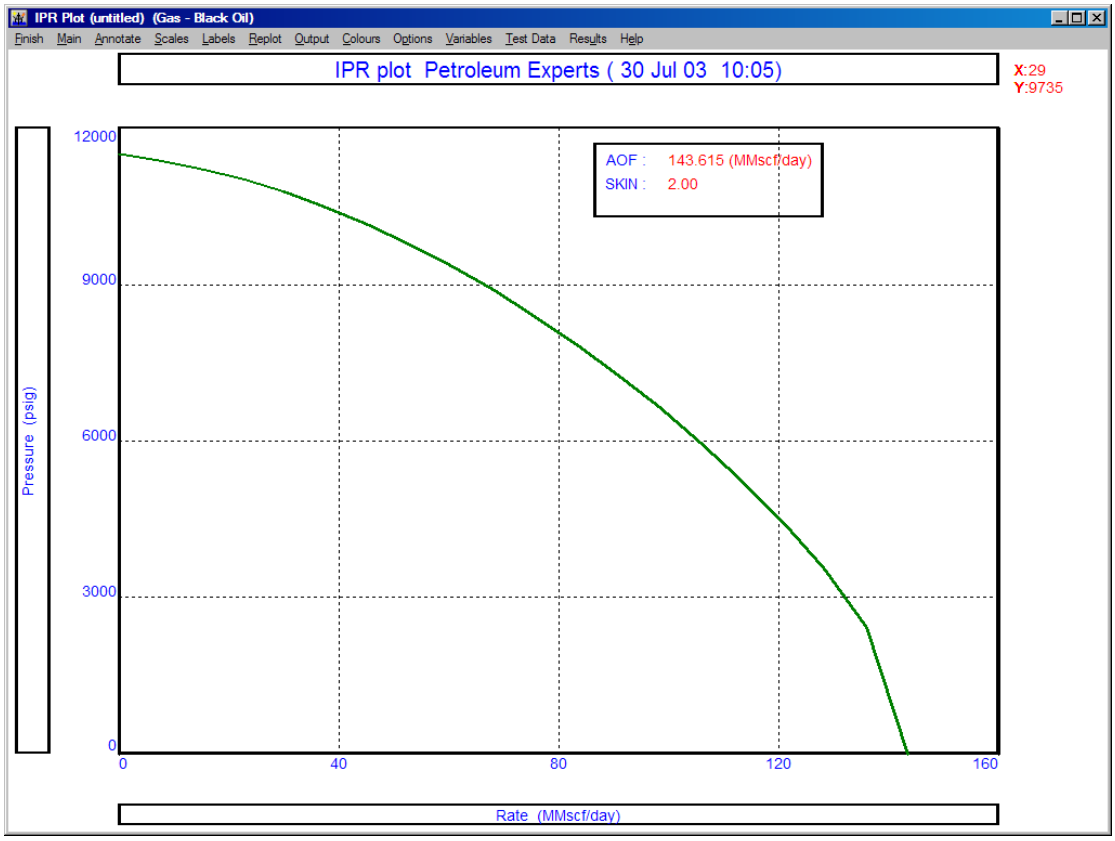


Figure 37: Inflow performance relation plot

When building field models and the answer for AOF is 150 MMscf/day, then note the y-axis minimum pressure is likely not be at 0 (zero). This is not maximum flow. Check the limits for maximum AOF. Select **Main** and then select **File | Preferences** and tab **Limits.** Note the **Maximum AOF for GAS** and change it to say **2000.** Select **Done | System | Inflow Performance | Calculate,** the displayed AOF will now be OK**.** The y-axis minimum pressure will be 0 (zero), i.e. maximum flow. Select **Main** to save the data and return to the main **PROSPER** window.

There is no production history to match data with so we will move on to the calculation phase to check that the IPR and VLP that had been defined appear reasonable. Select **Calculation | System (IPR+VLP)** and enter the following data.

- Top Node Pressure — 1500 psig
- Water Gas Ratio — 0 STB/MMscf
- Vertical Lift Correlation — *Petroleum Experts* 2
- Solution Node — Bottom Node
- Rate Method — Automatic - Linear

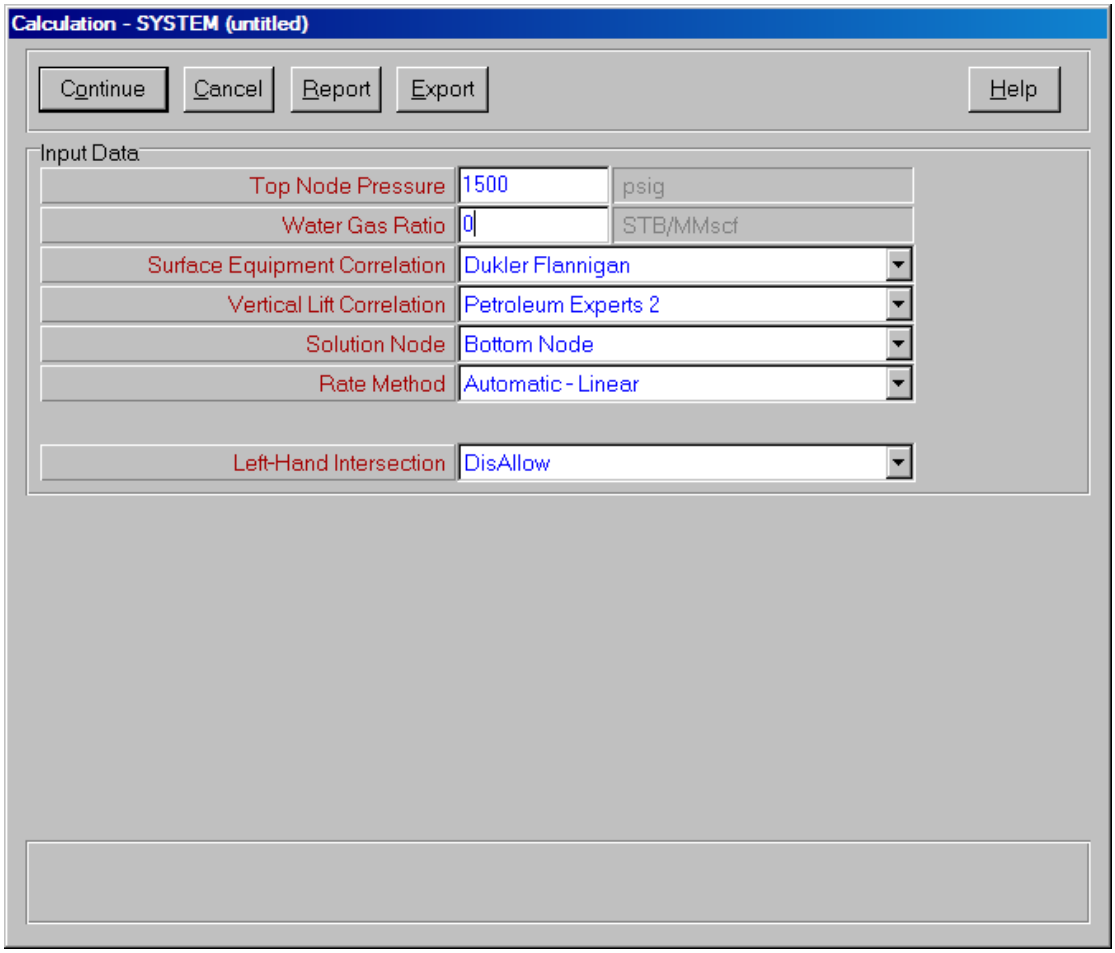


Figure 38: System calculation entry screen

Please note that although a WGR of 0 was entered, the program will use the Minimum WGR calculated in the ***PVT*** screen (vaporized water).

If matching had been performed, the correlations would have been chosen and fitted using non-linear regression. As it is, unmatched correlations will be used.

Select **Continue | Continue | Calculate** and allow ***PROSPER*** to perform the calculation. Confirm the end of the calculation by clicking **OK**. Scroll right (towards the bottom of the screen) within the Results display until the dP Friction and dP Gravity columns are shown. Notice that for moderate and large gas flow rates, the frictional pressure drop within the well dominates the gravitational pressure drop to such an extent that these flow rates are unlikely to ever be achieved, suggesting that perhaps a larger diameter well should be considered. Select **Plot** to display the results.

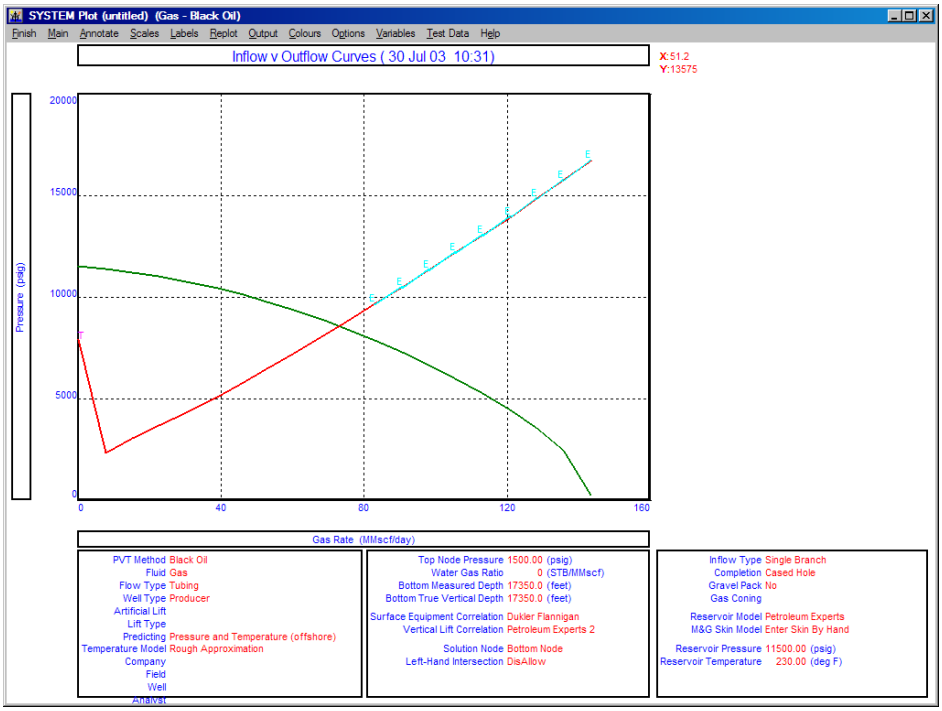


Figure 39: IPR and VLP Curves

The X-axis shows the produced gas flow rate and the Y-axis shows the well sandface pressure. The reservoir pressure has been set to 11500 psig and the well head pressure to 1500 psig. For these pressures, the IPR (blue curve) and VLP (red curve) intersect at a well sandface pressure of 8564 psig and flow rate of 73 MMscf/day, these being the flow conditions that the well would actually achieve (i.e. the unique flow pressure solution that lies on both the IPR and VLP curves). If the mouse cursor is moved within the plot, the X and Y coordinate values are displayed at the top right of the screen.

The relatively steep gradient of the VLP curve compared with the IPR curve indicates that most of the available pressure drop from the reservoir to the well head will be within the well as a consequence of its large frictional resistance.

Select **Finish** and note that the solution values are displayed on the right of the Calculation Output screen.

Select **Main** and **File |Save As** to save the ***PROSPER*** data. Enter the file name (Gasres.OUT) in a suitable directory, remembering not to overwrite a ***PROSPER*** file generated with an earlier version of ***PROSPER***, and then select **Done**.

If ***PROSPER*** was being run from ***GAP***, select ***GAP*** and return to the ***GAP*** Gas Network Example documentation, otherwise select **File | Exit**.

If you are following the example for building a ***GAP***, ***PROSPER***, ***MBAL*** model, you have been directed to jump to this **Section 2.2** from **Section 2.1.4** (pg. 14). You have now completed **Section 2.2**. Go back to pg. 14 now.

2.3 MBAL Gas Reservoir Example

This tutorial example is designed to provide a step-by-step introduction to the **MBAL** program. The emphasis is on the data entry required to model a dry gas reservoir for inclusion into a **GAP** model. See the **GAP** Gas Example 2.1 for further details. This example should be run using the standalone version of **MBAL**.

MBAL is a reservoir analysis tool that uses the production history of a reservoir and the **PVT** characteristics of the production fluid to perform mass balance calculations to estimate the Stock Tank Original Oil In Place (STOOIP) and identify the driving mechanisms within the reservoir (fluid expansion, formation expansion and aquifer inflow). Good **PVT** characterisation and production history are usually an essential input to an **MBAL** calculation, but for this tutorial example a minimum of input data is required.

With respect to the **GAP** Gas Example, the purpose of the **MBAL** model is to define the reservoir characteristics so that material balance prediction calculations can be performed by **GAP**.

2.3.1 STEP 1 : Initialise MBAL

Start the **MBAL** program by running **MBAL**.EXE, which can be found in the *Petroleum Experts* directory (default C:\Program Files*Petroleum Experts*\IPM 4.0). See the **MBAL** manual for more details on how to start **MBAL**.

If you are starting from **GAP**, double click on the tank and select **Run MBAL** button at the top of the screen.

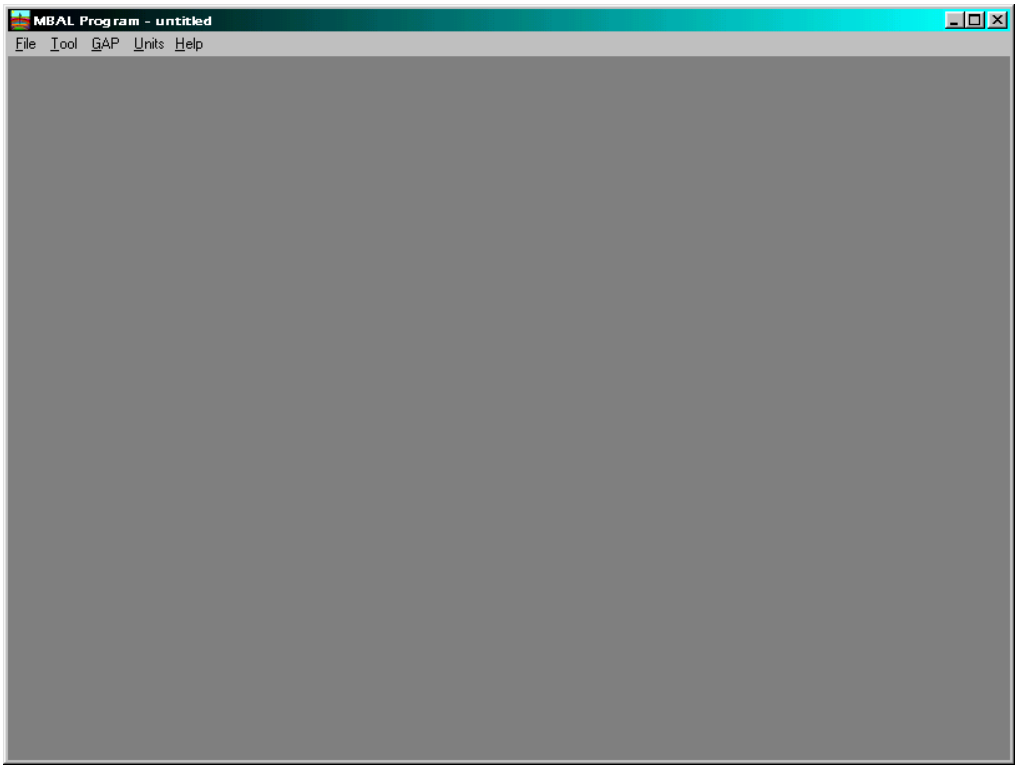


Figure 40: **MBAL** main screen

Check that the current version of **MBAL** has been loaded. Select **Help | About MBAL Package** to check the version number.

Select **File | New** to start a new file, and then select **Tool | Material Balance** to start an **MBAL** material balance session.

The command options (**File**, **Tool**, **Options** etc.) at the top of the **MBAL** window are laid out in a logical order (left to right) that reflects the order in which operations will usually be performed. Note that files saved with this version of **MBAL** *will not* be readable by previous versions. It is therefore recommended that the **File | Data Directory** option is set to point to a directory that is exclusively used to store data files created with the current software version.

It is important to ensure that consistent units are used throughout, particularly when data generated by **MBAL** may be incorporated into a **GAP** model. Oilfield units will be used for this example. Select **Units** to view the units used by **MBAL** for both input and output, as well as the expected data ranges. Near the bottom of the screen select **Oilfield** for both input and output units, and then select **Done**.

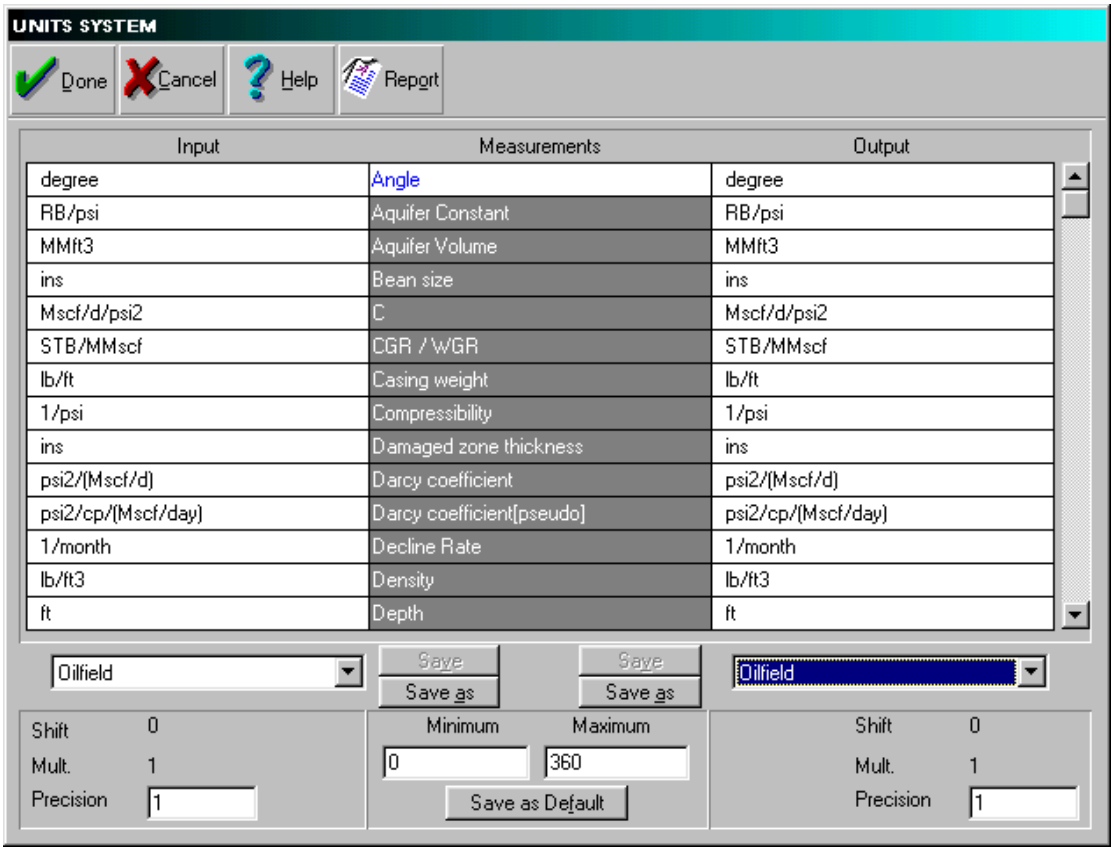


Figure 41: Oilfield Units for Input and Output

2.3.2 STEP 2 : Initialise MBAL Method Options

In this section the type of reservoir fluid and tank model that **MBAL** will use will be defined. Their detailed specification will be entered later.

This example has a dry gas reservoir. Select **Options** to display the System Options screen. This screen allows **MBAL** to guide you through the model set-up by only presenting the relevant screens as it is constructed. Set the options shown in the figure below and then select **Done**.

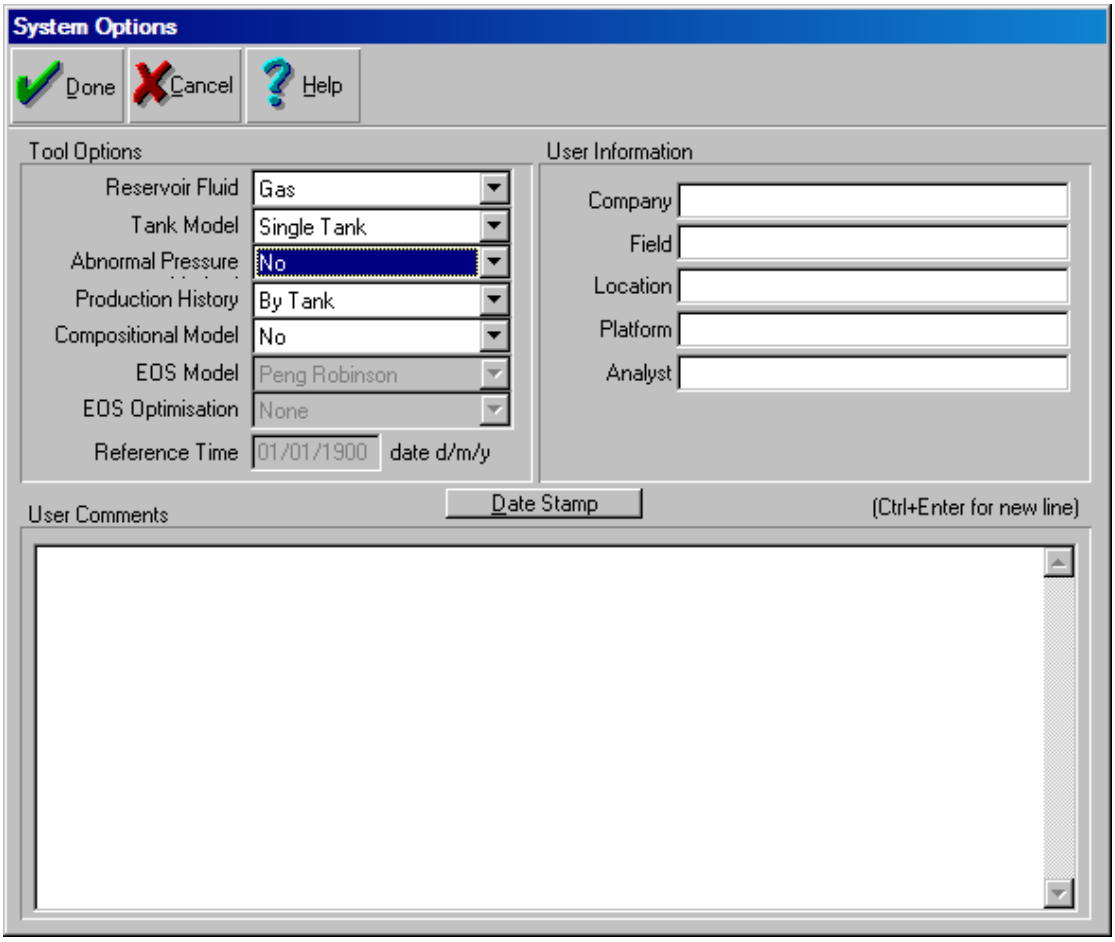


Figure 42: Completed System Options Screen

2.3.3 STEP 3 : Initialise PVT Data

This simple example will use an unmatched Black Oil **PVT** to characterise the reservoir fluid. Select **PVT | Fluid Properties** to enter the **PVT** data. Note the options to match correlations to data, or to use lookup tables of **PVT** data.

The **PVT** data used by **MBAL** must be the same as that used by **PROSPER** if an integrated **GAP** model involving **MBAL** and **PROSPER** is to be used. To aid this process, **MBAL** can import the **PVT** data used by **PROSPER** by using the **Import** button to import a **PVT** file generated by **PROSPER** (e.g. GASRES.**PVT**). If this is done, then the same matching to correlations or tabulated values must be initialised within **MBAL**.

If data is not imported from a **PROSPER** generated **PVT** file, then enter the data as shown in the figure below, and select **Done**. The condensate gravity of 50 API will not be used for a dry gas, but a value greater than 5 is required by default. See the **MBAL** manual for details on how to change unit range defaults.

Gas gravity	0.59
Separator pressure	100 psig
Condensate to Gas ratio	0 STB/MMscf
Condensate gravity	50 API
Water salinity	10000 ppm
Mole percent H2S	0 %
Mole percent CO2	0 %
Mole percent N2	0 %

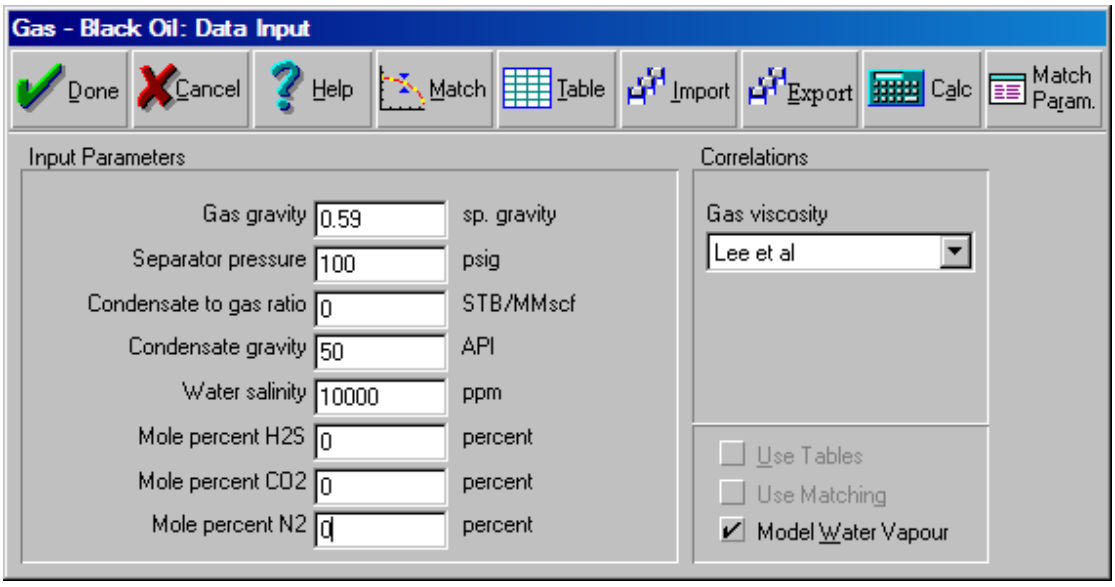


Figure 43: **PVT** Data Screen

2.3.4 STEP 4 : Initialise Tank Parameters

This step defines the physical properties of the reservoir required for material balance calculations.

From **MBAL** main screen, select **Input | Tank Data** to input the tank properties. Add the following parameters to each of the available tabs within the Tank Input Data screen. Use the **Validate** button at the bottom of the screens to validate the data input.

2.3.4.1Tank Parameters

- Tank Type Gas
- Temperature 230 degrees F
- Initial Pressure 11500 psig
- Porosity 0.2 fraction
- Connate Water Saturation 0.2 fraction
- Water Compressibility Use Corr 1/psi
- Original Gas In Place 600 Bscf
- Start of Production 01/01/2005

2.3.4.2Water Influx

- Model None

2.3.4.3Rock Properties

- Check the From Correlation button.

2.3.4.4Relative Permeabilities

- Rel Perm. From Corey Functions
- Water Sweep Eff. 100 percent

	Residual Saturation	End Point	Exponent
Krw	0.2	0.8	2
Krg	0.01	0.9	1.5

Note that the residual saturation for the water relative permeability corresponds to the connate water saturation.

There is no Pore Volume vs Depth or Production History data to be entered. Select **Done** when the data has been entered.

With no production history, no history matching is possible. Select **File | Save As** to save the **MBAL** data. Enter the file name GasRes.MBI in a suitable directory, remembering not to overwrite a file generated with an earlier version of **MBAL**.

If **MBAL** was being run from **GAP**, select **GAP**. Otherwise, select **File | Exit**.

If the **GAP** Gas Example is being followed then return to the **GAP** documentation, otherwise the **MBAL** Oil History Matching Example in the Physics section may be used to demonstrate the history matching features available in **MBAL**.

If you are following the example for building a **GAP**, **PROSPER**, **MBAL** model, you have been directed to jump to this **Section 2.3** from **Section 2.1.7** (pg. 22). You have now completed **Section 2.3**. Go back to pg. 22 now.

2.4 GAP Gas-Lifted System

The main objective of this example is to show how **GAP** can be used to optimize the gas lift allocation to gas lifted wells in a simple production system, and hence optimize the total oil production from the field.

2.4.1 Introduction

This tutorial not only offers a step-by-step guide to the setting up of the problem, but also gives an overview of other **GAP** functionality that can be used alongside, in addition to, or instead of the given approach. These points will be made in the body of the text.

It is advised that the step-by-step guide is followed on the computer, entering data as requested. We would encourage browsing around the system as you proceed through the guide: this can be a useful way of learning about other features of **GAP** that are not described here. For more detail on a particular feature, please refer to the main **GAP** manual.

Menu commands are described in this tutorial using (for example) the following scheme: File | Exit means select the Exit option from the File drop-down menu item.

2.4.1.1Definition of the Problem

The system that we are to set up is as follows:

- An oilfield has two gas lifted wells: well GL#1 and well GL#2.
- Each well is tied back to the riser base via a 1500 ft flowline.
- Each flowline has an ID of 5 inches.
- The riser is 500 ft long and has an ID of 10 inches.
- The platform is at 500 ft above the seabed. The seabed is assumed to be flat.

2.4.1.2Step-by-Step Approach

We summarise here the standard steps taken in building a network model from scratch. Although the actual steps taken in building a model will vary depending on the model, the following list gives an indication of the amount of work that needs to be done to set up an accurate field reproduction.

The steps to be followed are:

- Setting up the system.
- Drawing the system.
- Setting up the well models.
- Describing the surface network.
- Generating the inflow performances from existing well models.
- Generating lift curves for the wells.
- Allocating optimally the amount of gas available.
- Analysing the results.

2.4.2 Step 1: Setting up the System

At the end of this step we want to have initialised **GAP** ready for construction of the network. The steps are:

- Start a new file.
- Set up the optimisation method.
- Set up the units.
- Set up the gas injection source.

2.4.2.1Starting a New File

To start a new file, choose **File | New**. This option clears the current screen display and resets the program workspace to initial values.

2.4.2.2Setting up the Optimisation Method

To set-up the optimisation method, choose **Options | Method**

Select as Input Parameters:

- **Prediction: None**
  One can run predictive models in **GAP**, either using a simple decline curve model or by linking to *Petroleum Experts'* **MBAL** program to perform Material Balance calculations. Connectivity to Petroleum Expert's **REVEAL** numerical simulator can also be done.
- **System type: Production**

  Water and gas injection systems can also be modelled. When performing a prediction run, these injection systems can be associated with a production system to provide voidage replacement (for example) into the producing reservoirs.

- **Prediction Method: Pressure and temperature**
  This allows ***GAP*** to perform pressure and temperature drop calculations in pipeline models.

- **Optimisation Method: Production**
  You can also optimise with respect to revenue (in which case you must enter value parameters here).

- **Track composition: No**
  GAP allows fluid compositions to be tracked from the well (or reservoir) level to the top node. In this example, only black-oil properties will be reported.

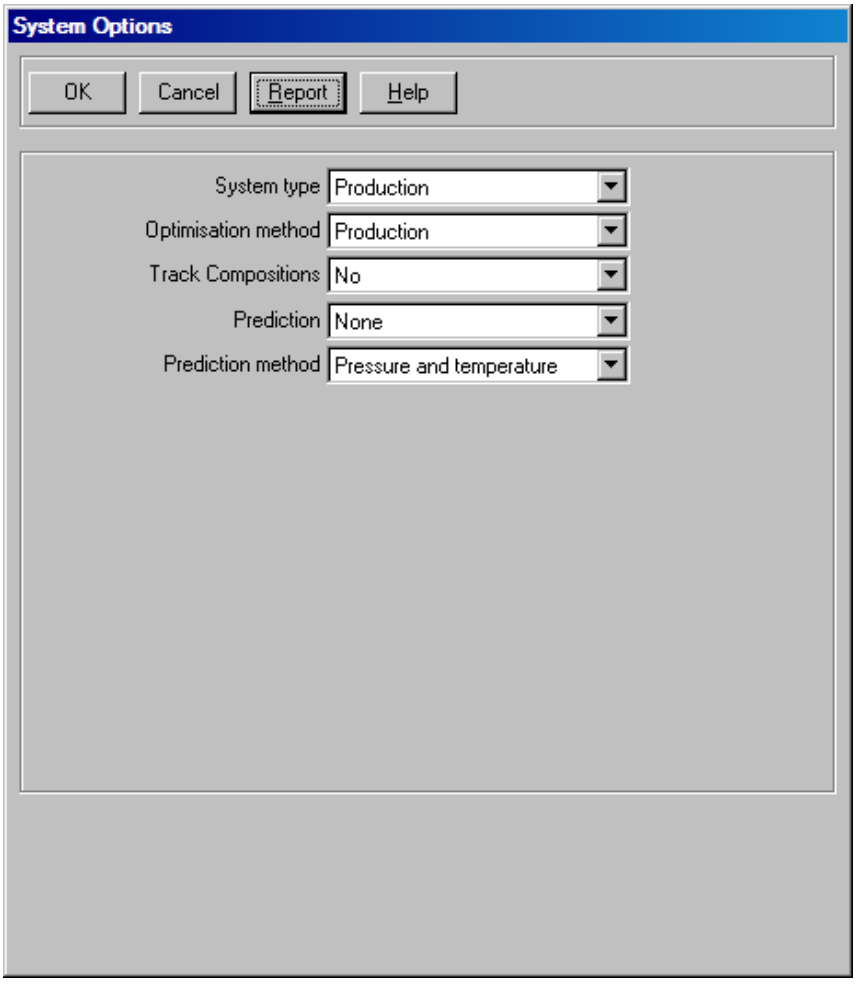


Figure 44: System options

The Ok button can now be clicked to finish this step.

2.4.2.3Setting up the units

To set-up the input and output units, click on **Options | Units** and select the unit system you want to use.

Clicking on the cell below the Input or Output column header (defaulted to Oilfield) will yield a selectable list of available units systems. This example will be worked in oilfield units throughout.

For more information, please refer to the online help or the **GAP** manual.

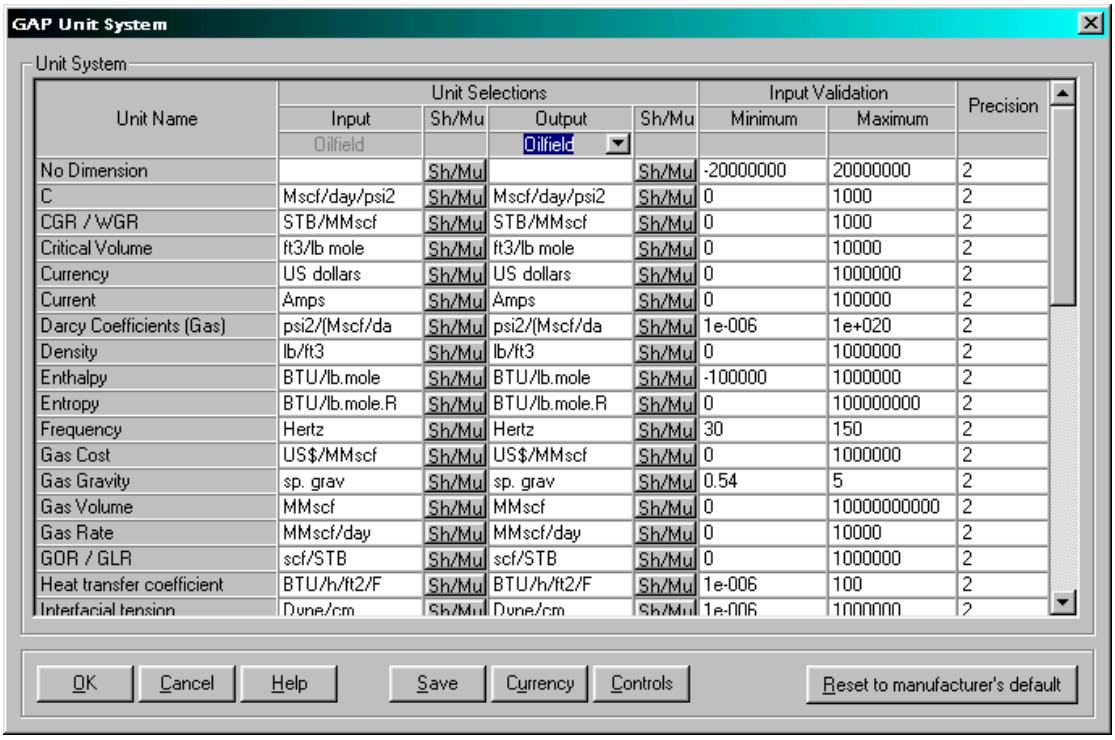


Figure 45: Setting up unit system

Click on **Ok** to complete this step.

2.4.2.4Setting Gas Injection Sources

If you have gas injection in your system, either for gas lifted wells or for gas injection into a reservoir during a prediction run, then it is convenient to set the gas injection parameters at this stage.

GAP maintains a list of gas injection sources with different gas gravities and impurity levels (and compositions if compositional tracking is enabled). These can be edited by selecting **Options |Injection fluids**. When a new file is created, a default entry is supplied with a specific gravity of 0.7 and no impurities. You may edit this entry, or add your own in the table.

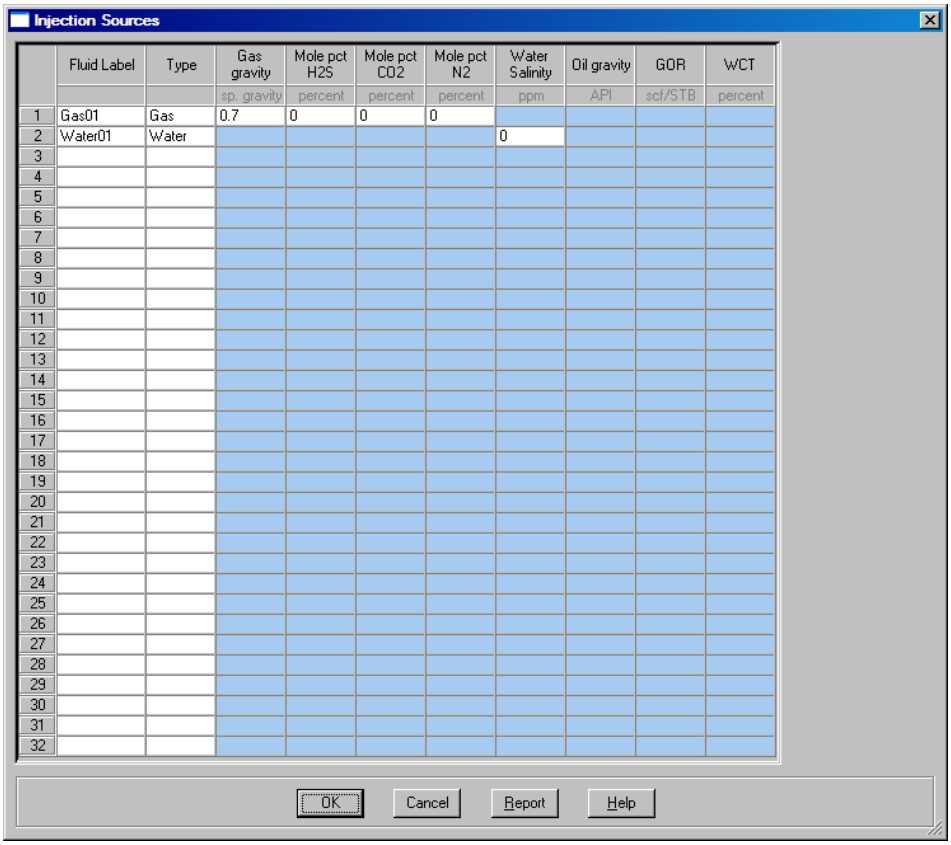


Figure 46: Gas lift gas properties setting

When you set up your gas lifted well models, you will be able to apply any source in the list to the well in question.

2.4.3 Step 2: Drawing the system

By the end of this step, we want to have a basic schematic set up on the main screen. The equipment data can be entered once the network is in place.

2.4.3.1Adding Wells

To create the wells icon, click on the 'Add Well' icon, from the toolbar. One may now click on anywhere on the screen and a well icon will be created at that point. Whenever an equipment icon is created, a label can be entered. Click **OK** once the well name is entered.
The first well will be labelled GL#1 and the second well GL#2. Users are encouraged to use real well names as labels for their wells.

If you want to move a well icon from one place to another on the screen, then hold down the |Shift key, point the cursor to the well icon and then move it to the desired place. Alternatively, select the Move tool from the toolbar and drag the item to the new location.

A well icon can be deleted by clicking on the Delete button on the toolbar and then clicking on the well icon that needs to be deleted. If a piece of equipment needs to be removed from the system temporarily, then it is preferable to Mask the item – select the Mask tool from the toolbar to achieve this.

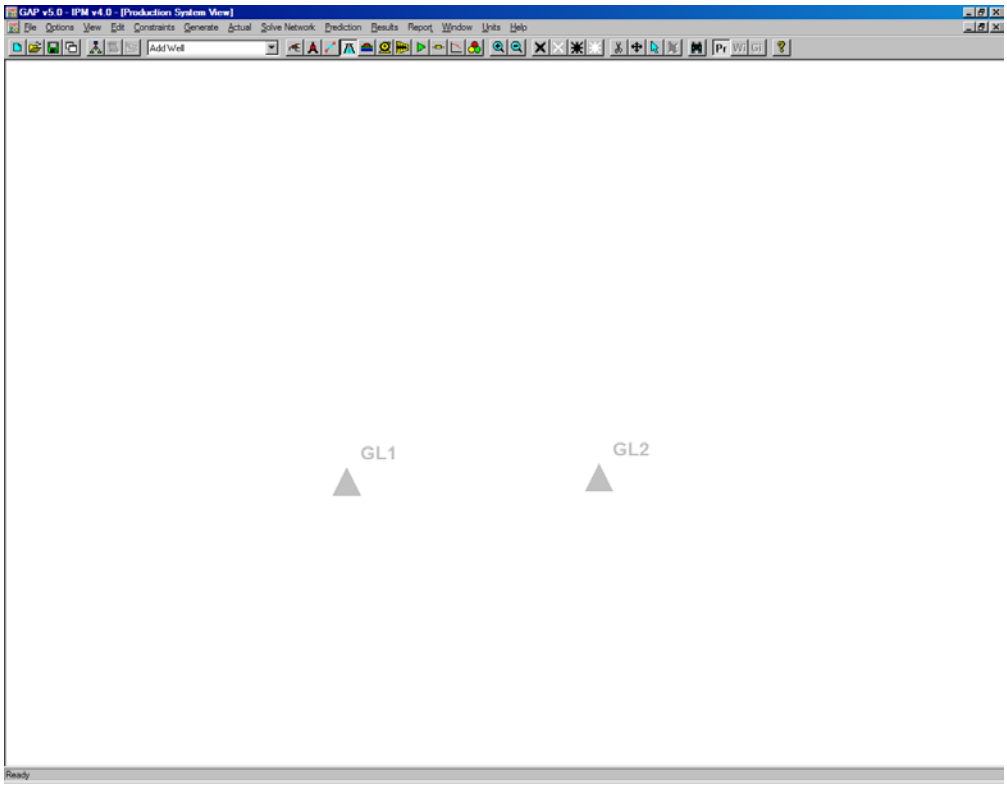


Figure 47: Two wells have been added to the system

See the **GAP** manual for more details on user interface functionality.

TIP: Buttons (such as 'Add Well') can be selected by clicking the right-hand mouse button in the window area to create a drop-down menu. Alternatively, the tools are also selectable from the toolbar buttons.

2.4.3.2Tie-backs

Joints are needed to hook up the wells to the tiebacks. Joints (or manifolds) are used as connection tools in **GAP**.

To create a joint icon, select the 'Add Joint' option from the toolbar. Click on the screen at the position where you would like the icon to be placed (above each well icon, for instance).

The joint to be connected to the well GL#1 will be labelled WH1-GL#1, and the second joint will be labelled WH2-GL#2. Again, users are encouraged to use real joint names as labels for their manifolds.

We will also need to create a third joint that will gather the production from the tiebacks. This will be labelled 'Collector'.

We will also need to create a fourth joint that represents the riser top. This will be labelled 'Riser top'.

These joints will be connected together with pipes at a later stage.

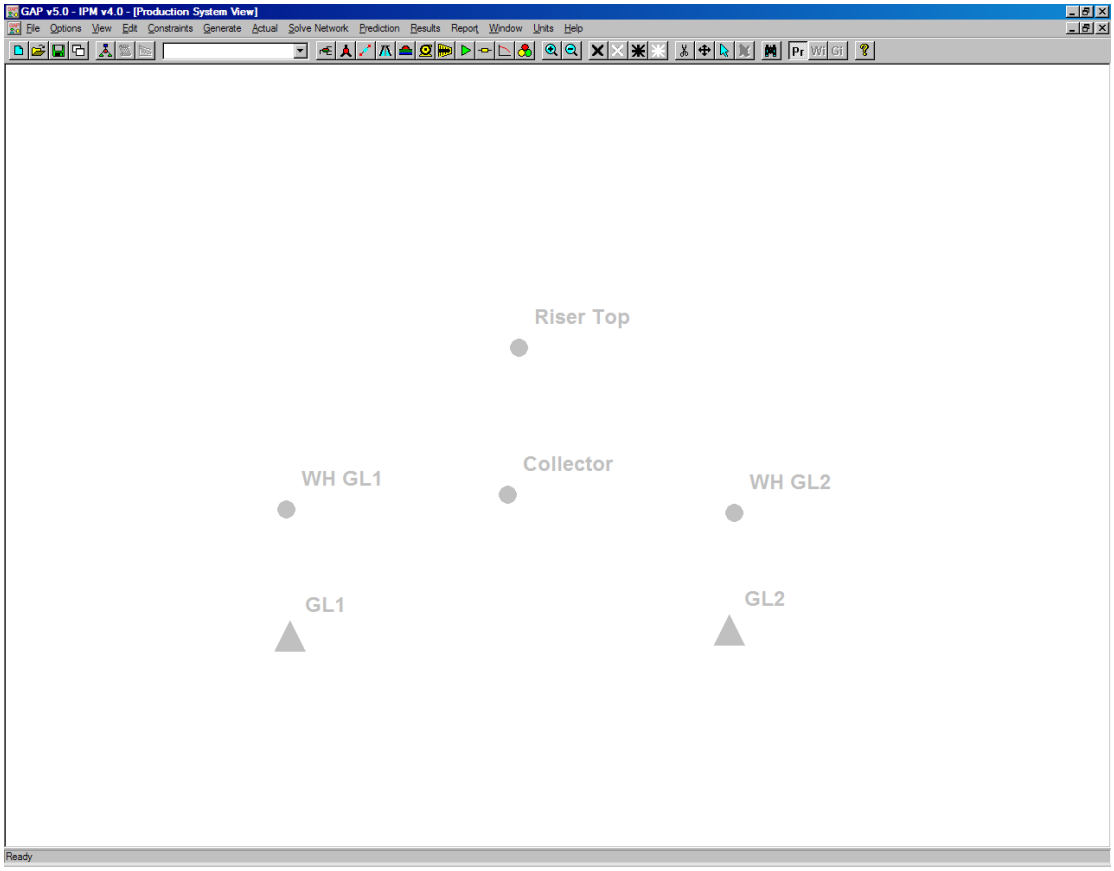


Figure 48: Joints have been added to the system

2.4.3.3The Platform

The platform is represented as a separator.

To create a separator icon, select the ‘Add Separator’ option from the tool bar. Click on the required location on the screen and an icon will be created, as above. This separator will be labelled ‘Platform’.

2.4.3.4Pipes/Links

➲ ***TIP:*** Pipes are created using the ‘Add Link’ tool from the toolbar. The reason for this name is that this tool can also be used to create logical connections (for example, well to reservoir, or compressor to manifold): whether a pipe or a logical connection is made depends on the equipment being connected

In order to connect the different equipment, we will now select the ‘Add Link’ option from the toolbar.
To hook up the well GL1 to the joint WH1-GL1, situate and click the cursor in the centre of the well icon GL1, and drag a connected to the WH1-GL1 icon.
Repeat the process with GL2 and WH2-GL2.
Repeat the process between WH1-GL1 and Collector and WH2-GL2 and Collector.
Link the Collector manifold to the Riser Top: this will become the *Riser*.
Finally, link the Riser top to the Platform.

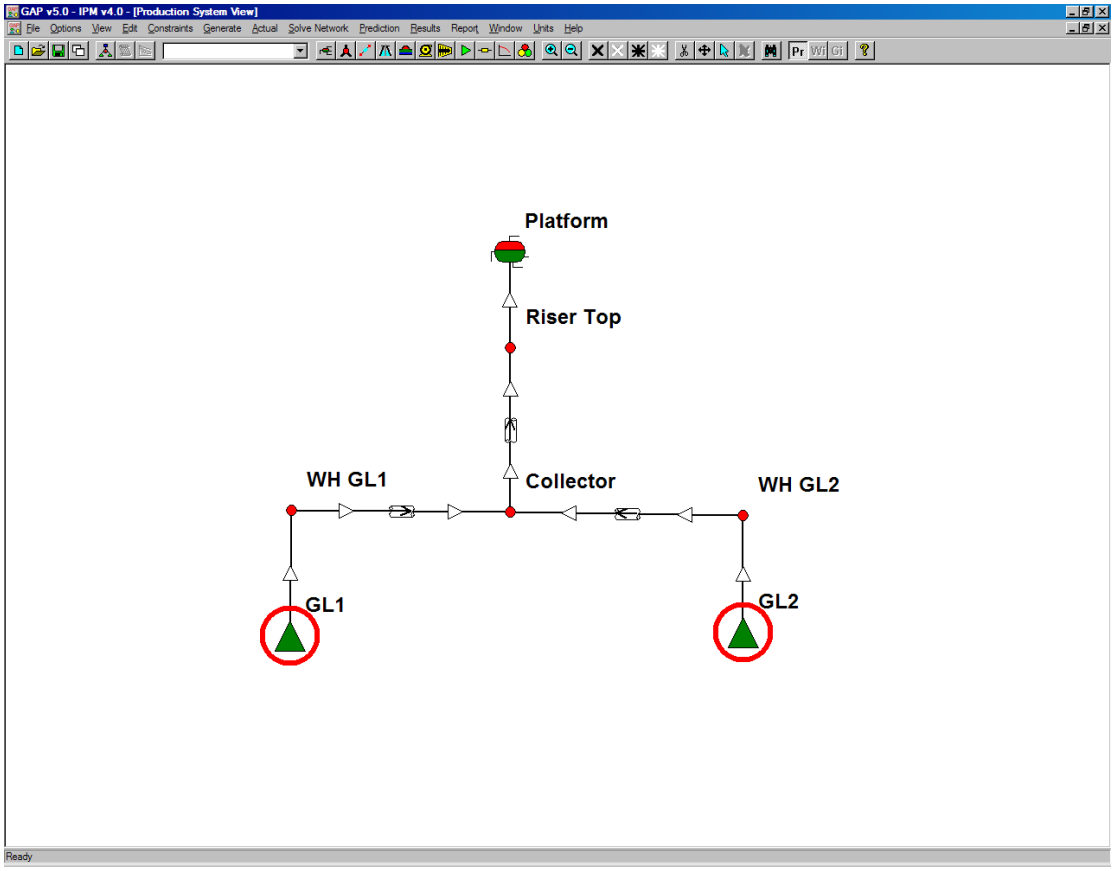


Figure 49: The whole system

Note: At this point, you will see that the pipes between the wells and the collector manifold, and the collector and the riser top, contain an icon to represent the flow-line data, whereas those between the wells and the wellhead manifolds, and that between Riser top and Platform do not. This is because ***GAP*** expects the well model to include all equipment up to the well head, and so does not attempt to model any pressure drops here. Pressure drops are modelled for all other pipes and depend on a pipeline description, as described below.

Labelling

The tieback between WH1-GL1 and the collector will be labelled 'TieOne'. The tieback between WH2-GL2 and the collector will be labelled 'TieTwo'.

To label the tieback between WH1-GL1 and the collector, double-click on click on the pipeline icon between the joint WH1-GL1 and the collector and enter in the label field 'TieOne'. Click on Ok to complete. Repeat for the pipe between WH2-GL2 and the collector. Repeat for the pipe between the collector and the riser, and label this 'Riser'.

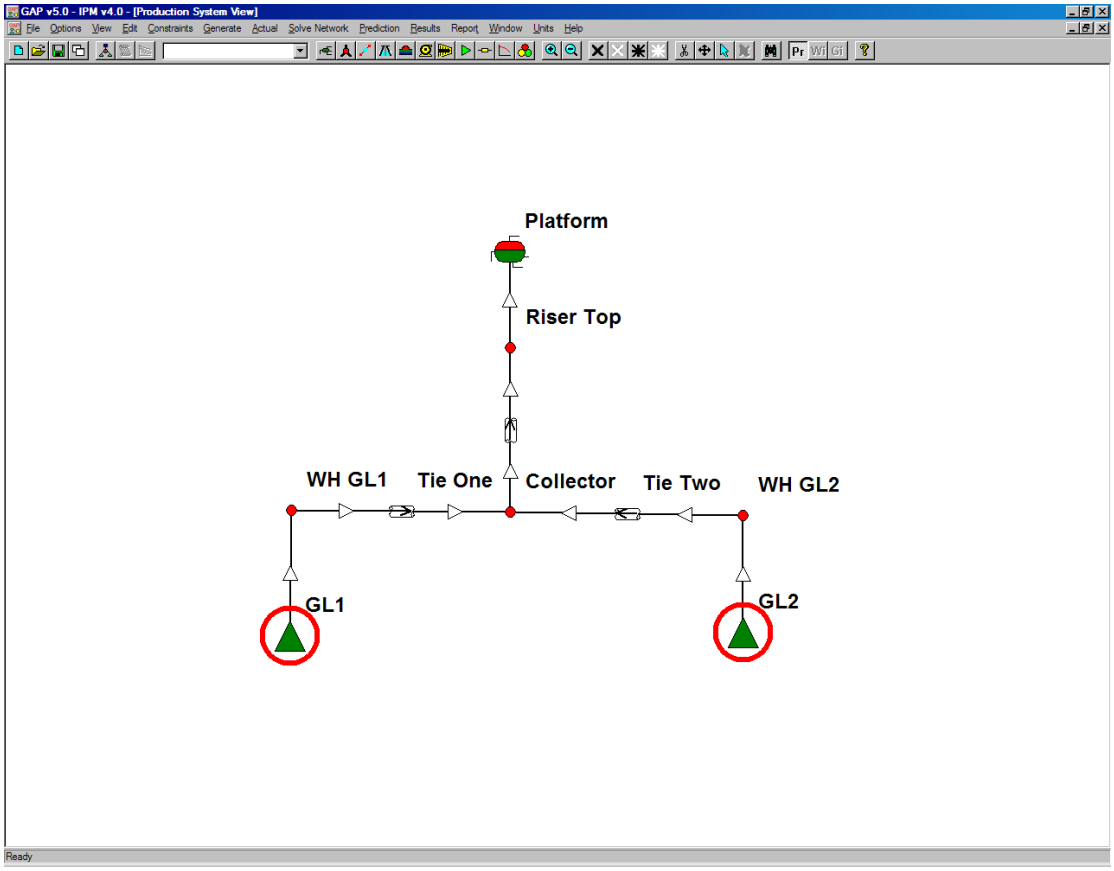


Figure 50: Labelling the pipeline

2.4.3.5Other Drawing Options

The user interface is configurable in several ways.

- You may want to give a name to the model. For this, click on **Options | System Summary** and enter the title 'Tutorial ***GAP*** Example' (for example). This text will now appear as a heading for the system network on the application screen.
- Clicking the right hand mouse button in the application screen and selecting the **Fonts** option can change the screen fonts. Clicking the right hand mouse button in the title can change the title font.
- Selecting **Icon Sizes** from the same drop-down menu can change the sizes of the icons on the ***GAP*** screen. This may be useful if building a large model.

Consult the user manual or online help for more options.

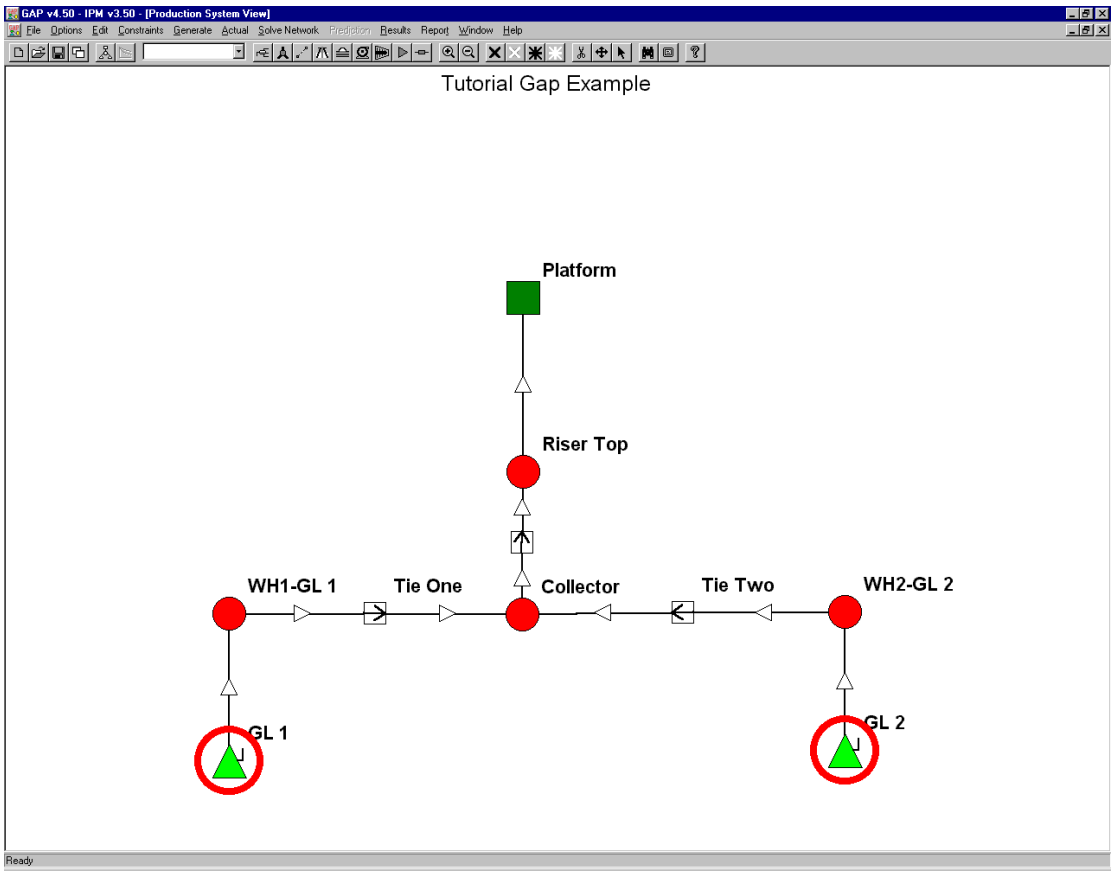


Figure 51: Labelling the system

The basic schematic is now set up, as shown above. The next step is to describe the equipment comprising the network.

2.4.4 Step 3: Describing the wells

By the end of this step, we want to have each network well modelled accurately.

It is recommended that the system is described from the wells to the top node. There are various quality checking functions that can be performed at the well level prior to building the whole system. These will be demonstrated in the following chapters.

TIP (note on entering equipment data): The basic means of entering data is from the equipment data entry screen. This can be accessed by double clicking on any equipment icon. The data entry screen consists of a data entry area and a list of network equipment. Descriptions of several pieces of equipment can be entered in one edit session by clicking on the entries in the equipment list to bring up different entry screens.

2.4.4.1Entering Well Data

Well GL1
To enter the equipment data entry screen, double click on the Well GL1 icon. This will lead you to the 'Well Data Entry - Summary screen' for this well. Enter the following data:

- **Label:** GL1
  This has already been set when the icon was created.
- **Mask:** Include In System
- **Well Type:** Oil Producer (Gas Lifted)
- **Well file:** \Program Files \ Petroleum Experts \ IPM 4.0\ Samples \ Worked Examples \ GL#1.out
  Wells can be modelled using *Petroleum Experts*' **PROSPER** package, as in this example. Enter the above **PROSPER** well file in this field, either typing it directly or using the 'Browse' button to invoke a file browser.
- **Model:** VLP/IPR intersection

Click on Ok to complete this step, or navigate directly to the next well.

Well GL2
The above comments apply also to Well GL2. Enter the following data:-

- **Label:** GL2
- **Mask:** Include In System
- **Well Type:** Oil Producer(Gas Lifted)
- **Well file:** \ Program Files \ Petroleum Experts \ IPM 4.0\ Samples \ Worked Examples \ GL#2.out
- **Model:** VLP/IPR intersection

Click on Ok to complete this step.

➔ ***Note:*** All the data here was entered on the summary screen. Note that the data entry screen is divided into three parts as indicated from the toggle buttons at the bottom right of the screen: *Summary*, *Input*, and *Results*. Click on the input and results buttons and have a look at the various categories of data that are available for entry or viewing: for example, the first tab on the input screen allows you to set up the gas lift injection source for the well.

2.4.4.2Generating IPRs From Existing *PROSPER* Well Models

By entering a well model file on the summary screen, we have associated this well with a **PROSPER** well model stored on disk. We can now import IPR data for the well directly from **PROSPER**.

When IPRs are transferred, **GAP** receives three points that lie on the **PROSPER** IPR along with **PVT** parameters and reservoir pressure. **GAP** then performs a match to this data to obtain the PI.

To transfer the well IPRs from the existing **PROSPER** well models, click now on Generate | Transfer Well IPRs from **PROSPER** and then follow the on-screen instructions. The following screen will be displayed:

GENERATE error
All
Select
Cancel
Help
No wells have been selected !
Press the <ALL> button to select all wells
and continue with Generate.
Press the <SELECT> button to highlight the
SELECT icon. You will then be able to select
individual wells to include in the generate
list and then re-start the Generate process

Figure 52: Generate error message

This is because we have not selected any well yet. Click on All to select all the wells.

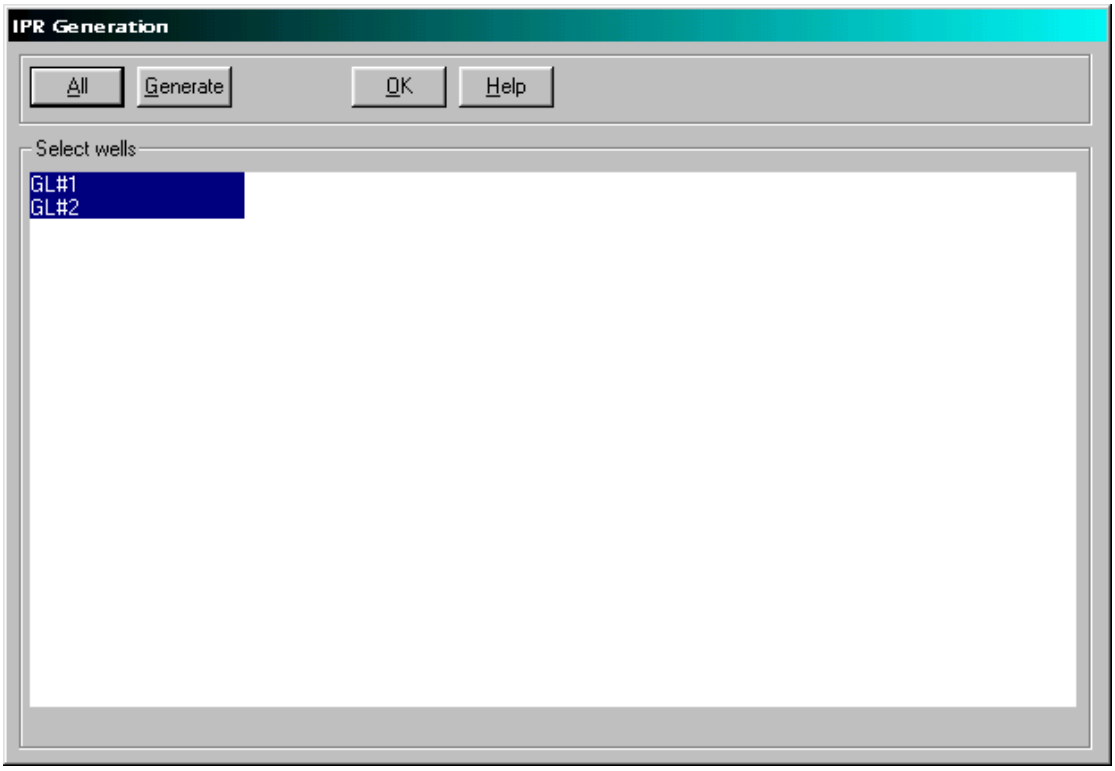


Figure 53: Select wells message

The screen above shows you the selected wells. Click on | Generate to proceed.

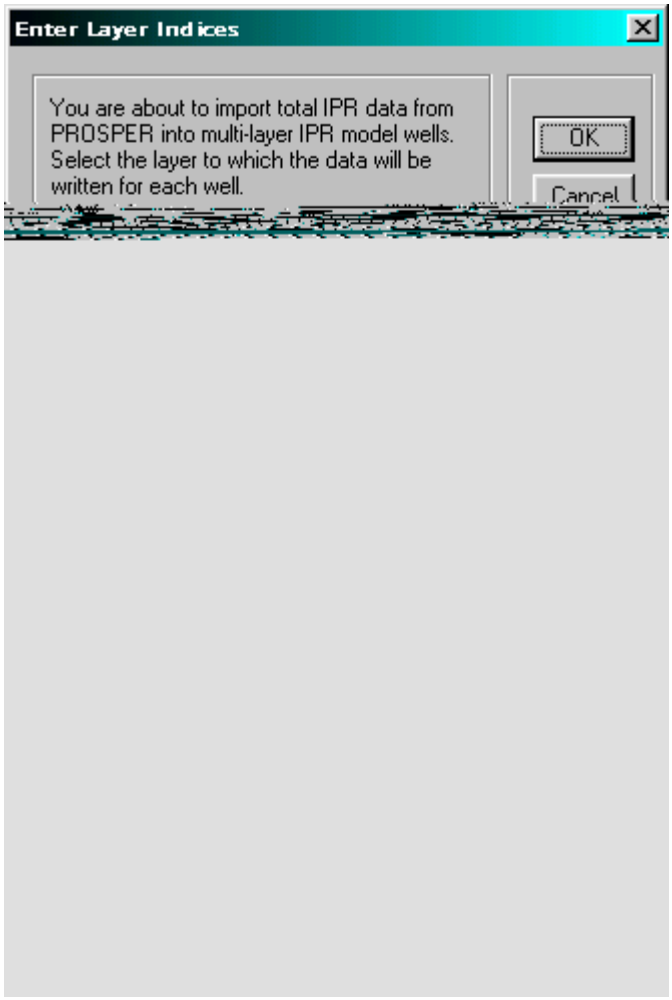

Enter Layer Indices
You are about to import total IPR data from PROSPER into multi-layer IPR model wells. Select the layer to which the data will be written for each well.
OK
Cancel

Figure 54: Select layer message

In **GAP**, you can model multilayer well. Each layer can have their own IPR. In this screen, you are going to tell **GAP**, about the IPR that it is about to read, belongs to which layer. If you have a single layer well, just leave the layer index as it is (layer 1). Click | OK to continue.

The IPR generation will begin and once started, the IPRs are transferred as a batch job and no user intervention should be required. When it finishes, you will have to minimise **PROSPER** in order to see the message:

Figure 55: IPR generation finish message

Click | OK to go back to the main screen. Double-click on the Well icon to bring up the well summary screen. Notice that the colour of the box next to the word 'IPR' has turned green. This indicated that the IPR generation has completed.

Now save the **GAP** file by clicking on , save the file as 'Tutorial Gas Lift Example.**GAP**'.

➲ ***Note:*** IPR parameters can be entered by hand and matched from the IPR input screen. From the well data entry screen, select the input button and navigate to the IPR tab. As you will note, this has been filled in automatically by the above process.

2.4.4.3Importing Existing Lift tables to the Well Models

A well is basically defined by an inflow and an outflow; the inflows (IPRs) have been already transferred to the wells in the above procedure.
In order to import/assign the VLP to the well GL#1, double-click on the GL#1 well icon, click on the **VLP** item (should be red if not valid) and, using the Browse button select the file \ Program Files \ Petroleum Experts \ Samples \ Worked Examples \ GL#1.VLP. Note clicking on the VLP item on the summary screen is equivalent to selecting the Input button followed by the VLP tab.

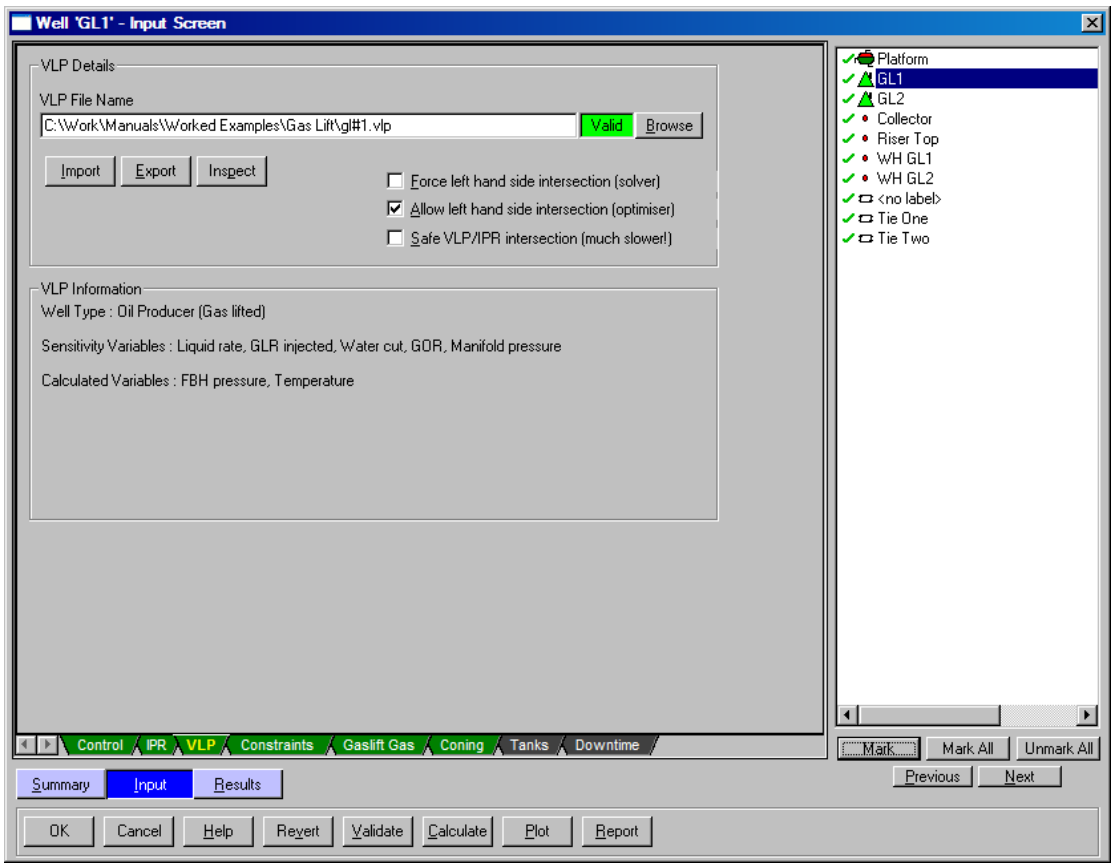


Figure 56: Assign the VLP files to the well

Repeat for the second well with file: \Program Files\Petroleum Experts\ Samples\Worked Examples\GL#2.VLP.

Lift curves can be plotted or inspected by clicking on the Plot buttons of the VLP screen.

Click on **Ok** to complete this step.

➲ ***Note:*** In this case we are simply assigning pre-calculated VLP files to the lift curve entries of the wells. In general use, you would have to create these files. Once a ***PROSPER*** file has been assigned to the well, lift curves can be calculated by ***PROSPER*** by selecting Generate | Generate Well VLPs. Alternatively, ***GAP*** can import .TPD files (generated by ***PROSPER***) to make .VLP files. To do this, click on Import on the VLP screen and select the required import file.

2.4.5 Step 4: Describing the Network

At the end of this step, all the remaining network equipment will be modelled.
In the following discussion we enter true vertical depths (TVDs) with respect to the platform. Thus we define the platform to be at zero ft TVD such that the collector and tiebacks are at 500 ft TVD.

2.4.5.1Riser Description

To describe the riser, click on the pipeline icon between the collector and the platform, labelled 'Riser'. This will lead to the 'Pipe Data Entry - Summary Screen'.

Enter the following data:

- **Correlation:** Petroleum Experts 4
- **Correlation Coefficients:** 1 and 1 (default)

Now go to the input screen (by clicking on the 'Input' button) and enter the following:

- **Environment:** default
  This can be used to set up special pipe environmental quantities such as ambient temperature or heat capacities. The default entries are suitable for our requirements.

Finally, we enter the physical description of the pipe. Go to the 'Description' tab and enter the following:

- Enter 0 ft for the downstream TVD (Platform)
- Point the cursor to the first cell in the second row in the 'Segment Type' column and select 'Line pipe':
- Length: 500 ft
- TVD: 500 ft
- ID: 10"
- Roughness: 00006" (default)

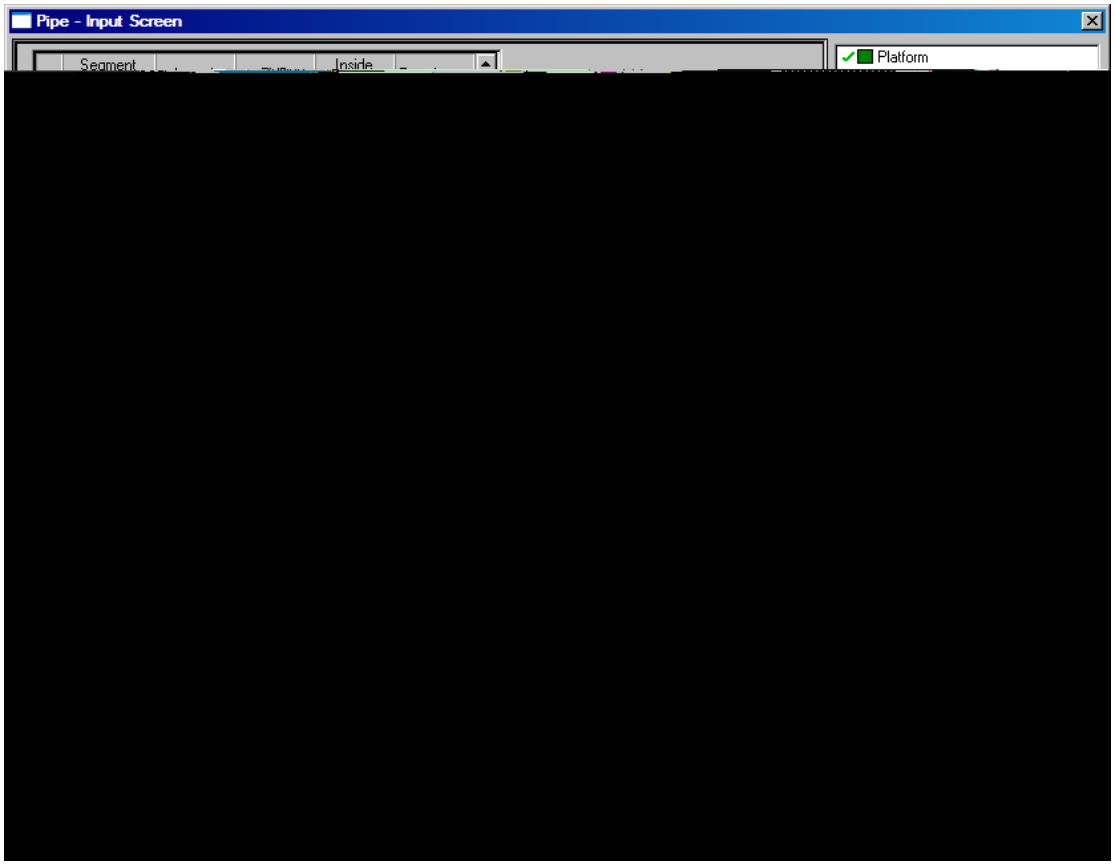


Figure 57: Riser description

➲ ***TIP:*** If you have real data for your pipeline flows, then it is a good idea to match the correlation that you are using to this data. To do this, click on the Match button of the description entry screen and follow the instructions detailed in the on-line help or the user manual.

➲ ***TIP:*** If you do not enter pipe data, then the pipe will be treated as a simple logical connection between two nodes, and zero pressure drop will be modelled across it. ***GAP*** does not insist that you enter pipe data.

Click on **Ok** to complete this, or navigate to the next pipe.

2.4.5.2Description of the tie-back ‘TieOne’

The above process detailed for the riser is repeated for the other system pipes.

- **Correlation:** Petroleum Experts 4
- **Correlation Coefficients:** 1 and 1 (default)
- **Environment:** default

The pipeline description is:

- Enter 500 ft for the downstream end (Collector)
- Select ‘Line pipe’ in the first cell in the second row in the ‘Segment Type’ column.
- Length: 1500 ft
- TVD: 500 ft
- ID: 5"
- Roughness: 00006" (default)

Figure 58: Tie One Description

Navigate to the final pipe.

2.4.5.3Description of the tie-back ‘TieTwo’

- **Correlation:** Petroleum Experts 4
- **Correlation Coefficients:** 1 and 1 (default)
- **Environment:** default

The pipeline description is:

- Enter 500 ft for the downstream end (Collector)
- Select ‘Line Pipe’ in the first cell in the second row in the ‘Segment Type’ column.
- Length: 1500 ft
- TVD: 500 ft
- ID: 5"
- Roughness: 00006" (default)

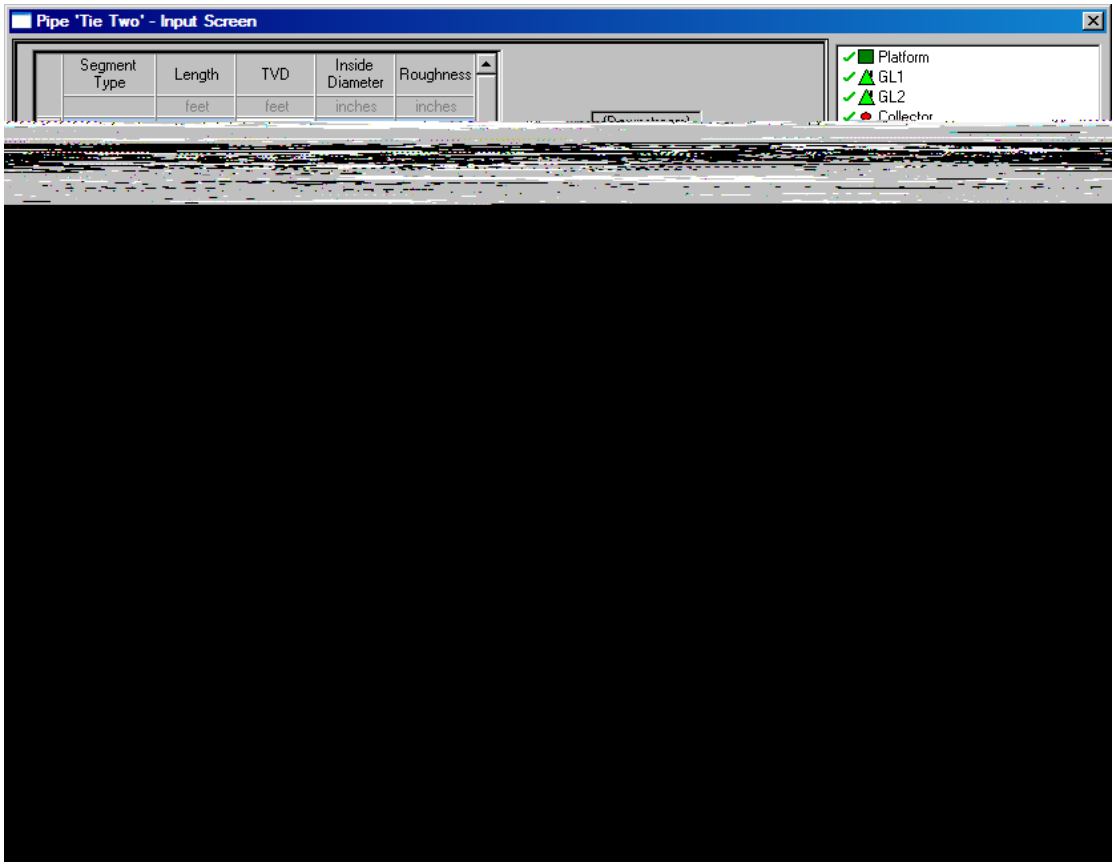


Figure 59: TieTwo Description

Now click on **Ok** to complete this.

2.4.6 Step 6: Allocating the Amount of Gas Available

We are now in a position to allocate gas lift for optimum production. In this step, we want to determine (given a total quantity of available gas) the optimum amount of gas to be injected in each well.

In order to perform an optimisation, click on **| Solve Network** and then enter different amount of gas lift gas available.

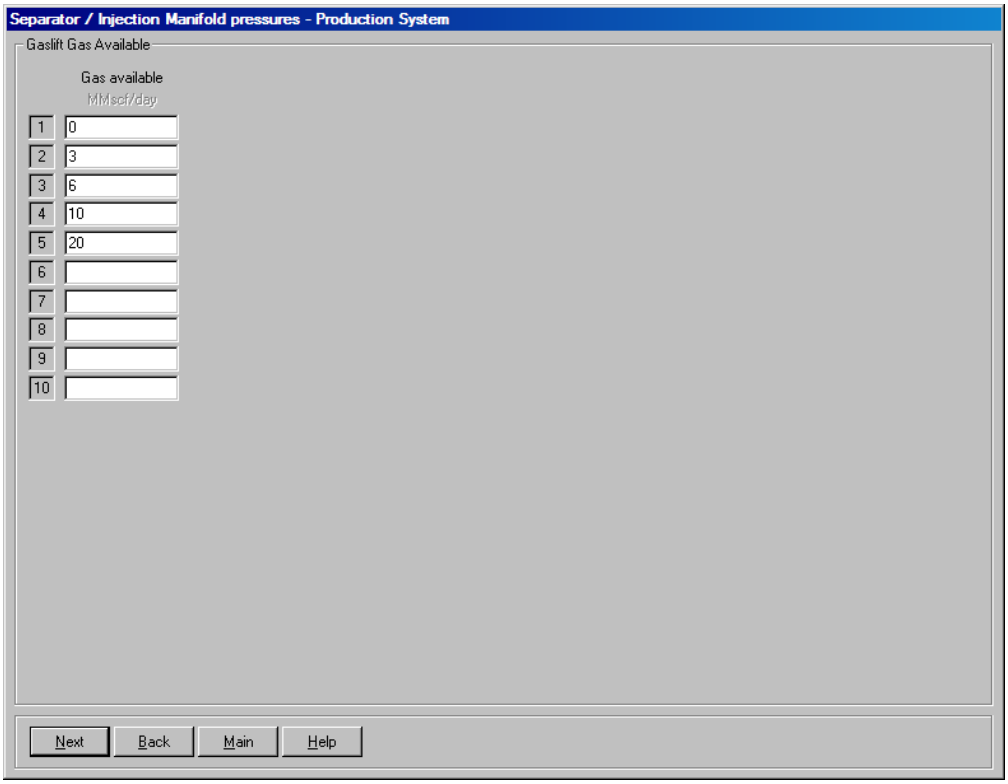


Figure 60: Specifying cases with different gas lift gas available

Gas available (MMscf/d)
0
3
6
10
20

Click on **| Next**. For the platform pressure, enter 250 psig.

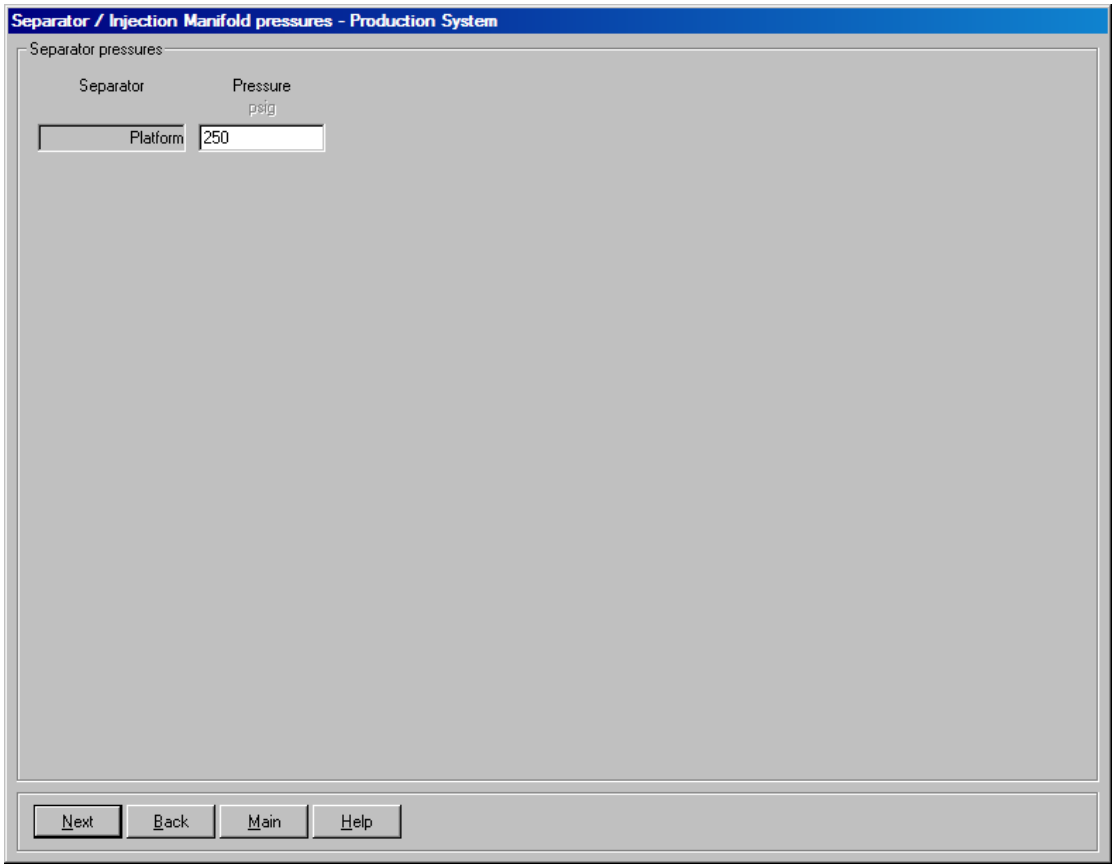
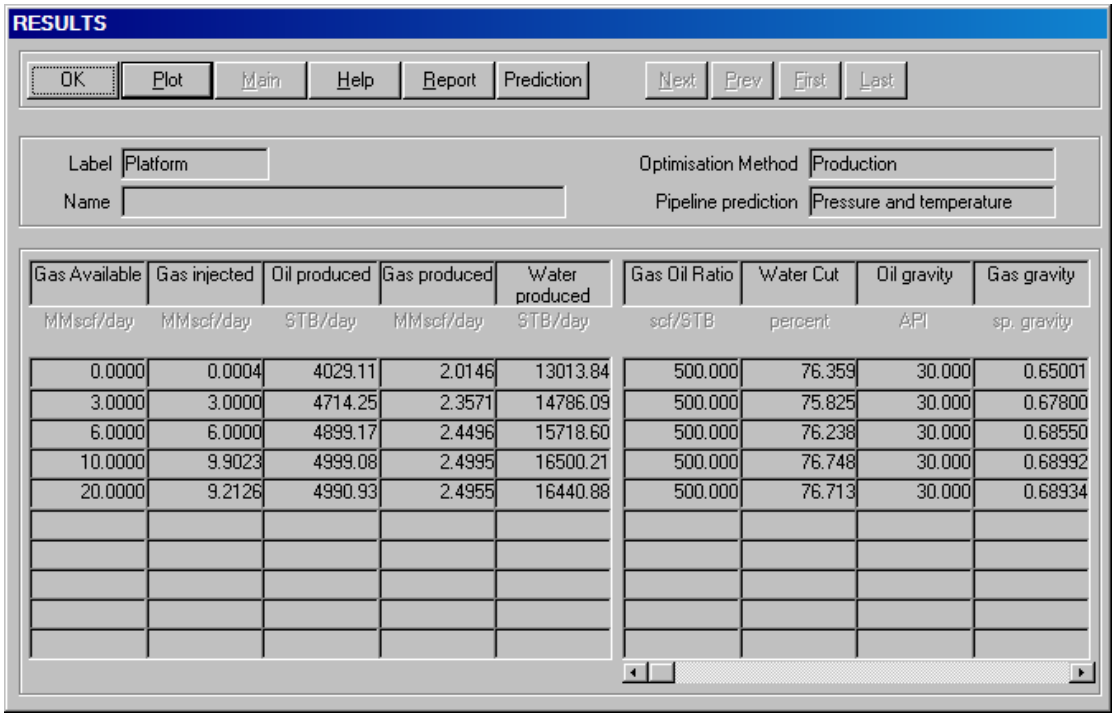


Figure 61: Specifying the separator pressure

Click on **| Next | Calculate**. Make sure that the 'Optimise and Honour Constraints' check box is ticked before the calculation is started. ***GAP*** is going to allocate the available gas to the wells to maximise the oil production. When the calculation is finished, click on **| Main** to go back to the main screen.

2.4.7 Step 7: Analysing the results

To see the effect of the optimised injection of increasing amount of lift gas, click on **Results | Detailed | All Separators** and a screen similar to this is displayed:



Gas Available	Gas injected	Oil produced	Gas produced	Water produced	Gas Oil Ratio	Water Cut	Oil gravity	Gas gravity
MMscf/day	MMscf/day	STB/day	MMscf/day	STB/day	scf/STB	percent	API	sp. gravity
0.0000	0.0004	4029.11	2.0146	13013.84	500.000	76.359	30.000	0.65001
3.0000	3.0000	4714.25	2.3571	14786.09	500.000	75.825	30.000	0.67800
6.0000	6.0000	4899.17	2.4496	15718.60	500.000	76.238	30.000	0.68550
10.0000	9.9023	4999.08	2.4995	16500.21	500.000	76.748	30.000	0.68992
20.0000	9.2126	4990.93	2.4955	16440.88	500.000	76.713	30.000	0.68934

Figure 62: Allocation results

The natural flow production of this production network system is about 4000 BOPD. With 6 MMscf/day of gas injection, an optimal allocation would increase the production to around 4900 BOPD.

We also see from these results that increasing the total gas injection beyond 10 MMscf/day does not increase the amount of production. The maximum production available from this system is nearly 5000 BOPD.

A plot of oil production against lift gas injection can be displayed by clicking on **Plot**.

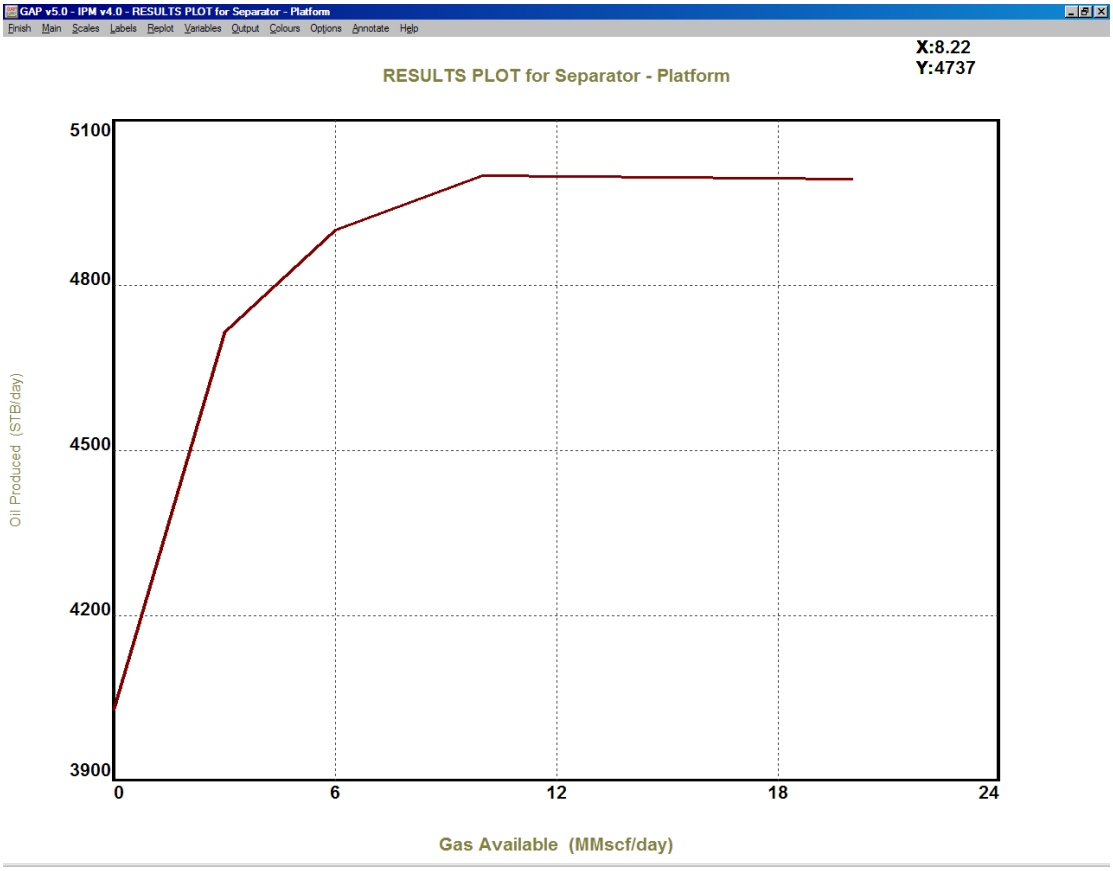


Figure 63: Allocation results

The optimal contribution/distribution between the wells can be viewed by clicking on **Results | Summary | All Wells**. Select 'Gas Injection' from the spin box at the top of the screen to display how the amount of gas injection to each well varies with total amount available. You may click on Plot for a graphical view. Select as variables:

- **Gas available:** MMscft/d
- **Y axis variable:** Oil produced

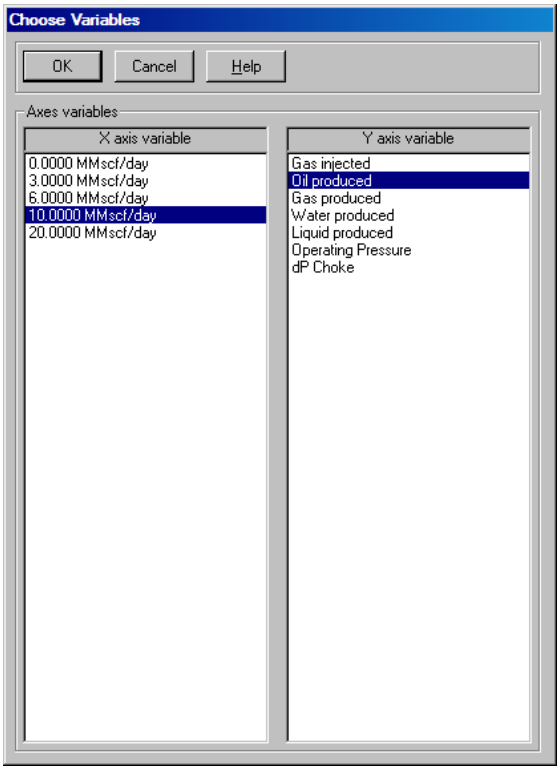


Figure 64: Select variable to plot

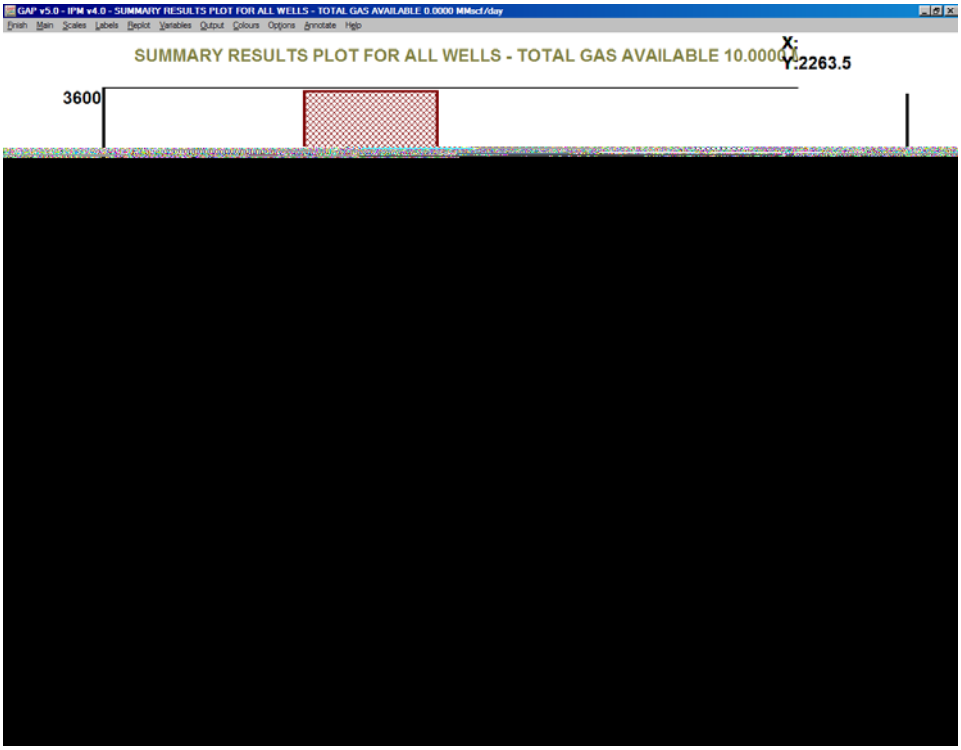


Figure 65: Oil produced from each well

TIP: You can view and plot allocation results for any node in the system by entering its data entry screen in the usual manner and then clicking on the Results button. The first tab displays the Allocation results. Press Plot to obtain a plot of these results.

2.4.8 Step 8 – Associated Water / Gas Injection Model

In this section a water injection model will be linked to the previously build production model. A materal balance prediction will be run on this model.

2.4.8.1Set the Production Model

The production model used is the gas lifted production model previously created, to which a reservoir has been added in order to be able to run a material balance prediction.
The procedure to add a reservoir has been described in the first **GAP** example developed in the tutorial.

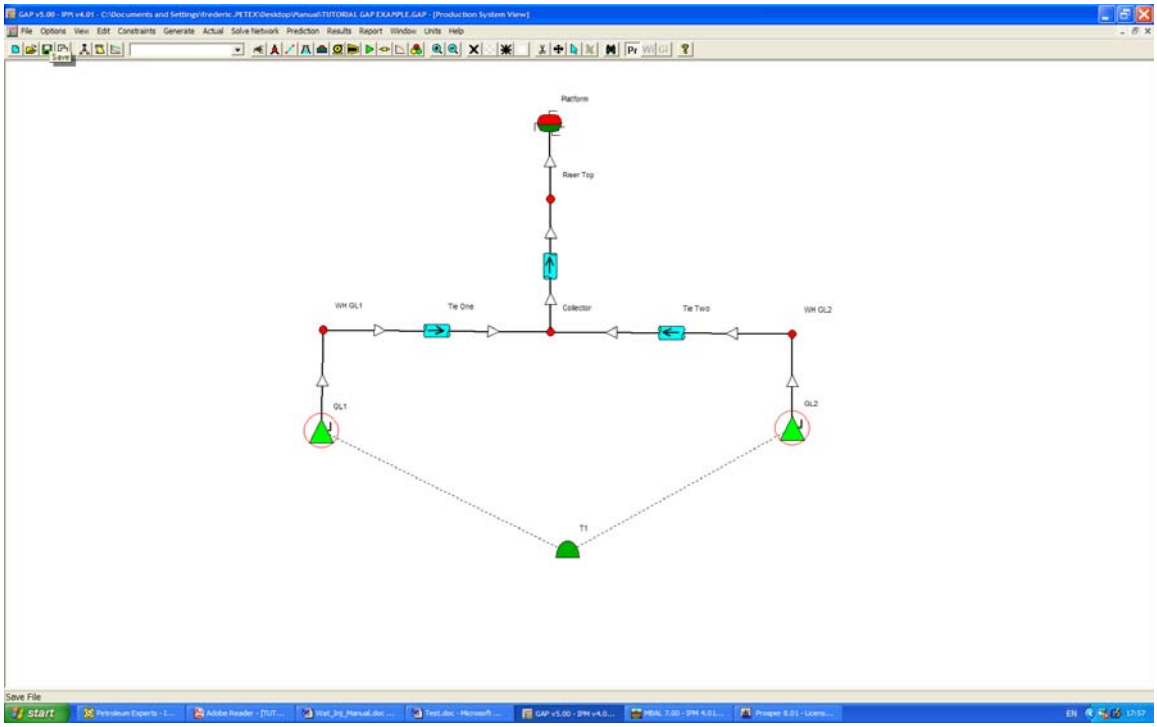


Figure 66: Schematic Diagram of the Production Model

In order to be able to run a material balance prediction, we need to set the model to be a predictive model. To do so, go to **Options | Method** and select **On** with the scrollbar related to **Prediction**.

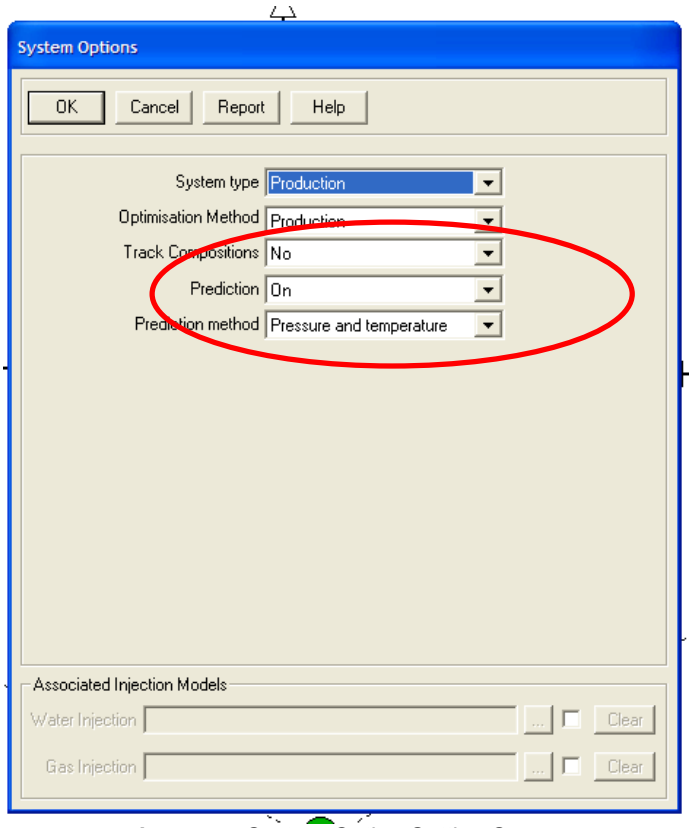


Figure 67: System Option Setting Screen

The relative permeabilities corresponding to the reservoir have been described in the tank model. Double click on the well, go to **Input | IPR | More** and set Prediction Fractional Flow Rel Perm to **From Tank Model**.

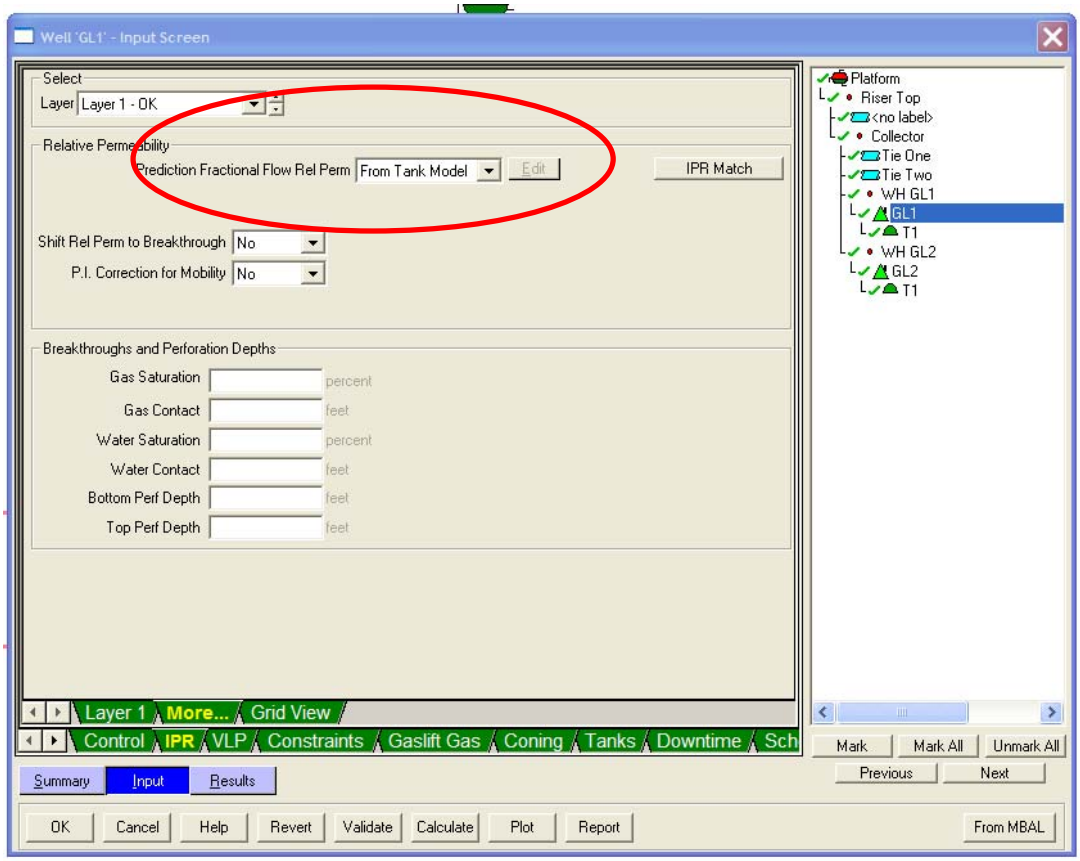


Figure 68: Schematic Diagram of the Production Model

The production model is then set in order to run a material balance prediction.

Use **File | Save As** to save the work done this far to a **GAP** file (TUTORIAL **GAP** EXAMPLE.**GAP**) in a suitable directory.

2.4.8.2Create the Water Injection Model

The first step is to create an independent **GAP** model to model the water injection system.
Go to **File | New** to create a new **GAP** file.
In order to set the model to water injection go to **Options | Method** and select **Water Injection** in the system type scroll bar. As this model is going to be linked with a production model and as a material balance prediction is going to be run, select **On** in the prediction scrollbar. Click **OK** to validate the data.

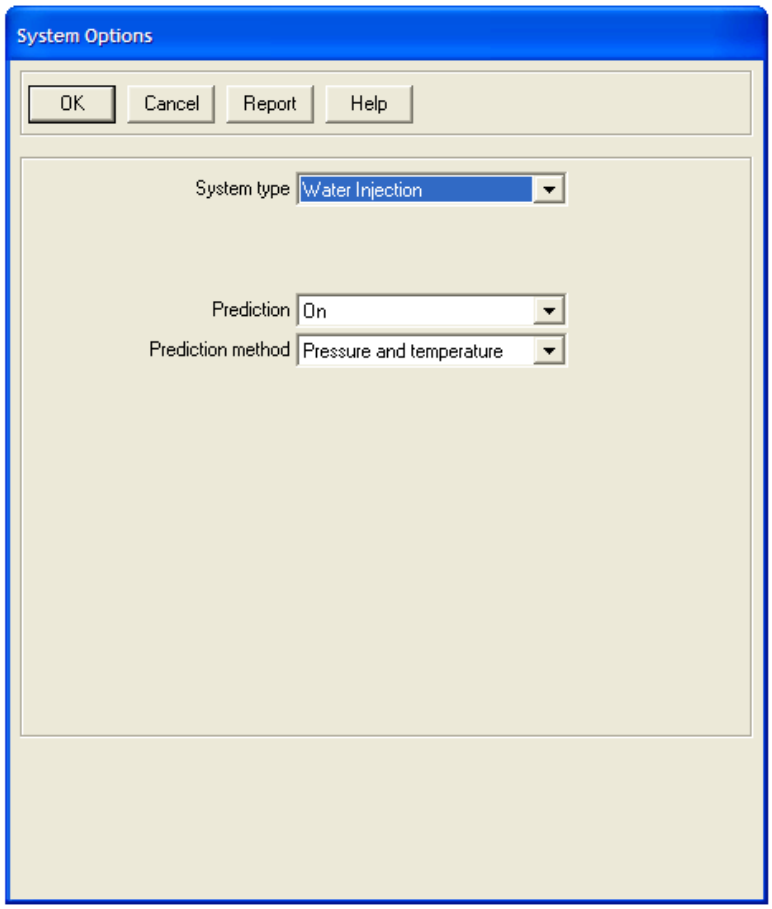


Figure 69: Water Injection Model Settings

The next step is to implement the elements constituting the model : reservoir, water injection wells, injection lines and injection manifold.

In the main **GAP** screen, click on the icon and add a tank.

Using the icon, add a well.

Using the icon, add a water injection manifold.

Using the icon, add two joints in between the water injection manifold and the well.

Using the icon, link all the elements together.

The network described on the following figure is obtained.

Figure 70: Schematic Diagram of the Water Injection Network

Use **File | Save As** to save the work done this far to a ***GAP*** file (WaterInj.***GAP***) in a suitable directory.

We need now to specify the physical properties of the different elements constituting the system. The procedure has been explained in detail for each element when the production network has been created.

The tank needs to be described as the same tank used in the production model. Select **Browse** to locate the ***MBAL*** file (TUTORIAL ***GAP*** EXAMPLE_TANK.MBI).

The water injection well needs to be created using the same procedure described for the production wells. IPR and VLPs must be generated as for any other type of well. The injection flow line can be characterised by implementing some pipe data : pipe length, pipe inside diameter, pipe inlet and outlet TVD as normal.

The following network can then be set up :

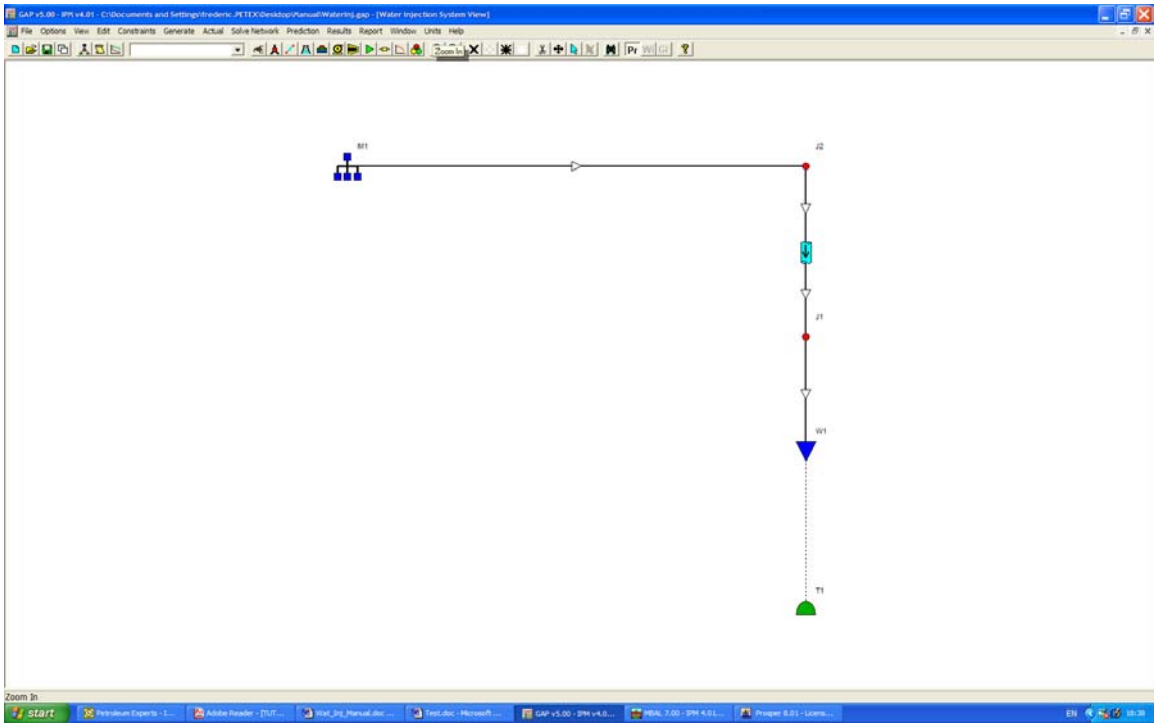


Figure 71: Schematic Diagram of the Water Injection Network

The red circles around the tank and the well are not present anymore, confirming the validity of the data input on each element of the system.

Use **File | Save As** to save the work done this far to a ***GAP*** file (WaterInj.***GAP***) in a suitable directory.

2.4.8.3Link the Production and the Injection System

The next step is to link the production model and the water injection model.

To do so, open the production model file in ***GAP***. Go to **Options | Method** and tick the box corresponding to **Associated Injection Models | Water Injection**. The browsing box will then be available. Browse the water injection model previously built. The path corresponding to this file will appear.

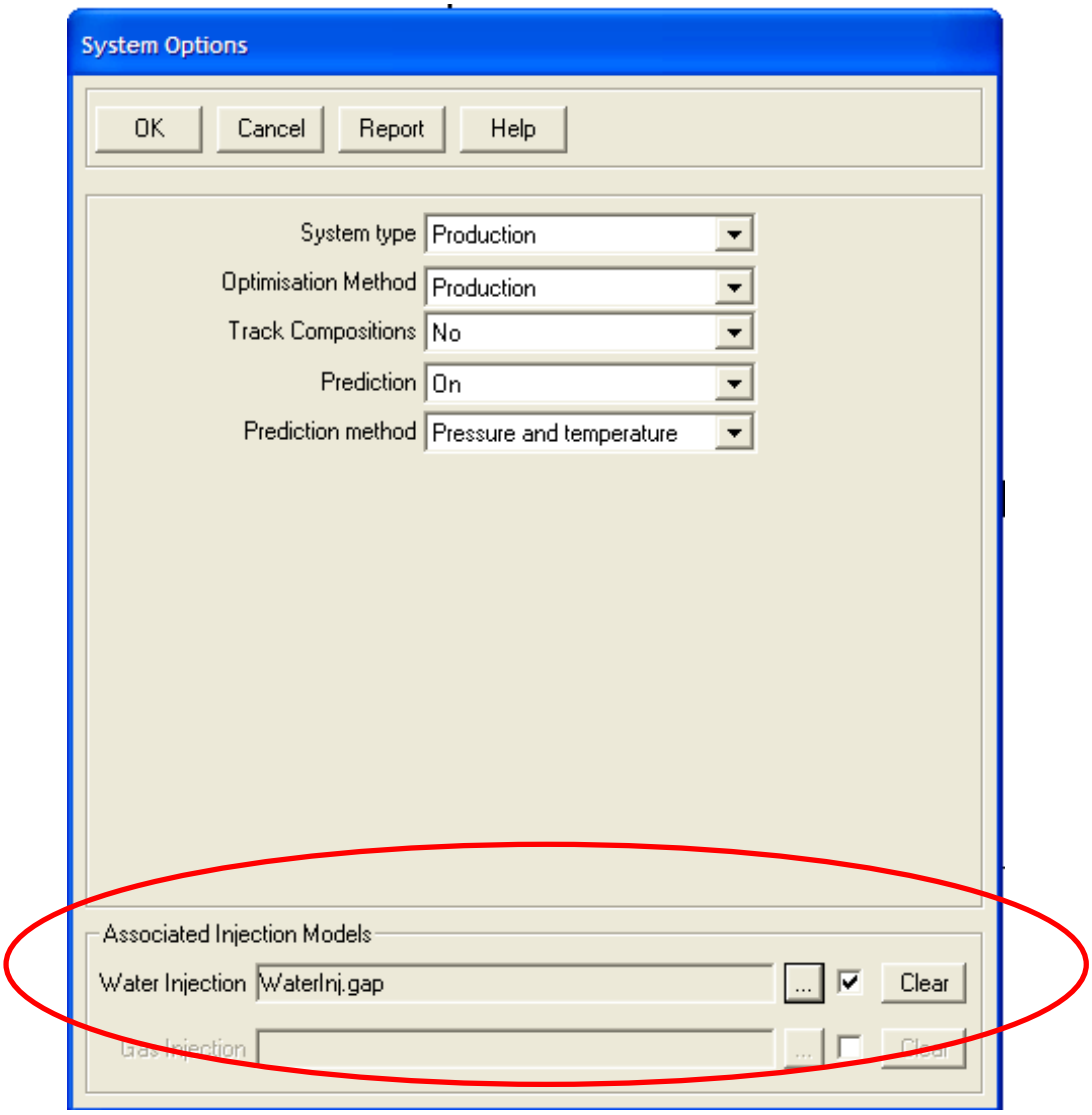


Figure 72: Linking Production and Water Injection Models

Click OK. Both the production and injection models are going to appear in the **GAP** main window.
One way of visualising both systems in the **GAP** main window, go to **Window | Tile Vertically.**

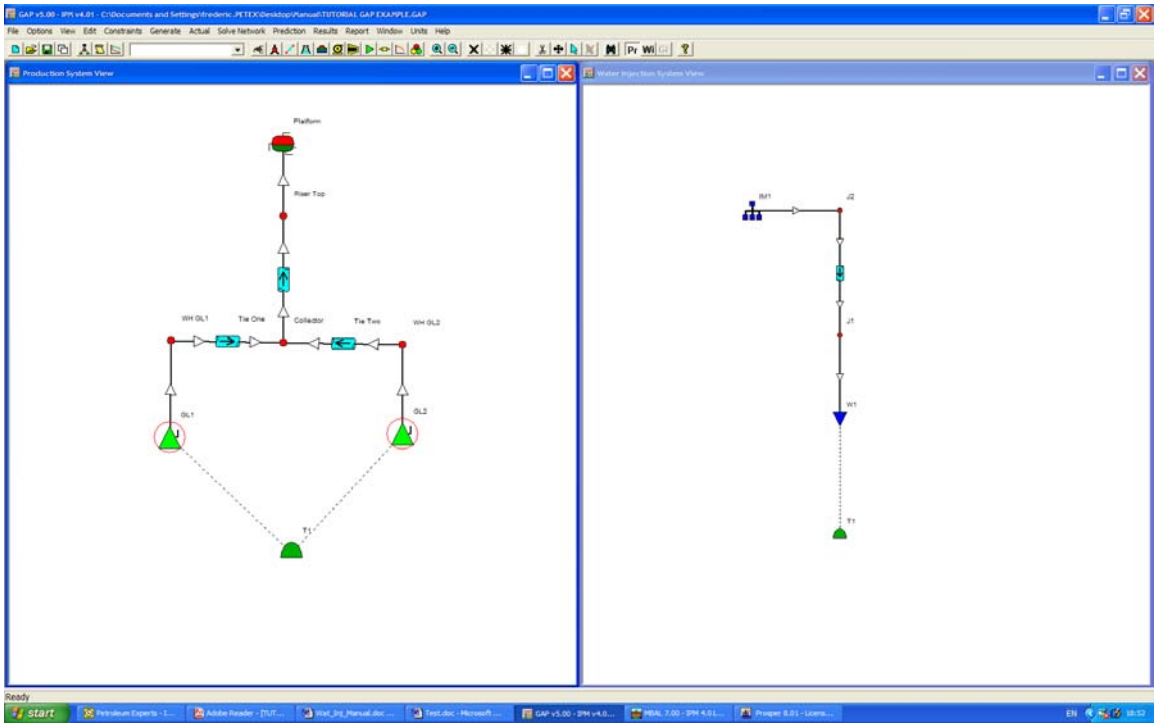


Figure 73: Schematic Diagram of both Production and Water Injection Network

It is now possible to make modifications on each model using the same **GAP** session.

Use **File | Save As** to save the work done this far to a **GAP** file. Each model will be saved separately as shown by the following screen. Click **Continue** if you wish to save the production and water injection models in the same directories chosen previously. If this is not the case, simply alter the file path name in the saving screen.

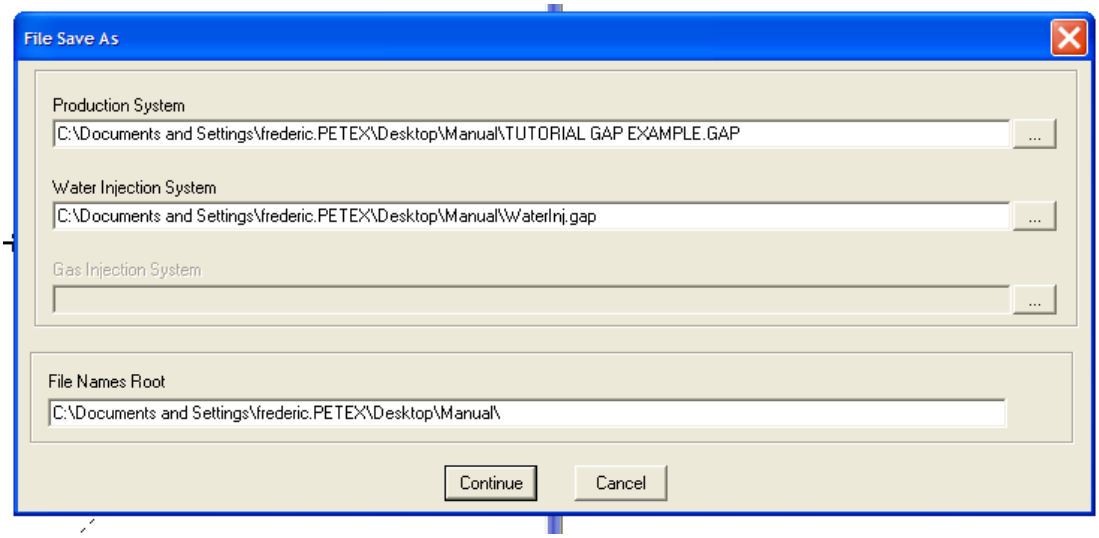


Figure 74: Saving Both Production and Water Injection Systems

2.4.8.4Running the Material Balance Prediction

A material balance prediction can now be run.

Using the icon, start the material balance prediction process.
The first screen enables the selection of the prediction starting date, ending date and step size.

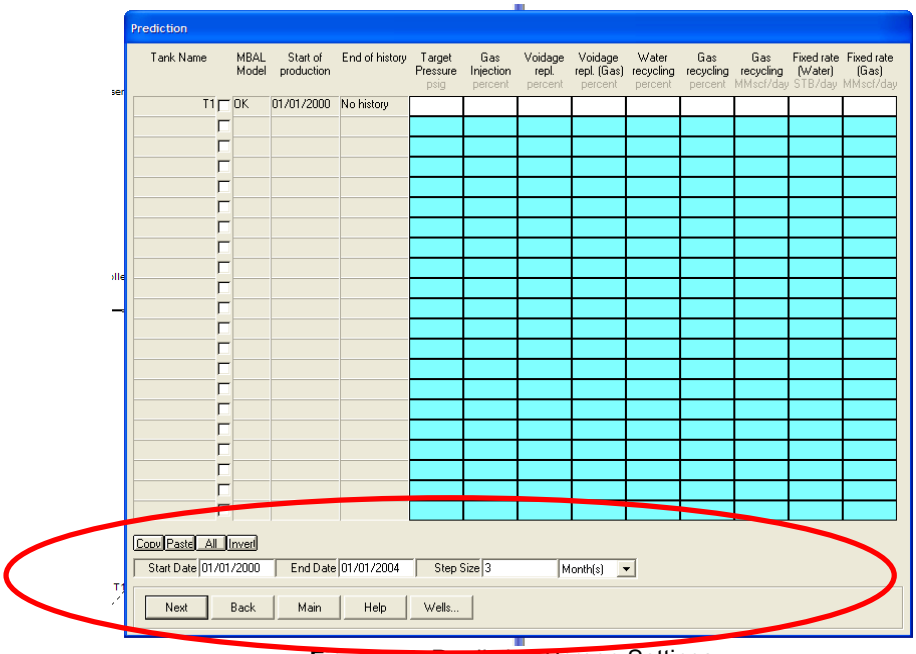


Figure 75: Prediction Screen Settings

Several options are available in order to control the water injection (i.e. or gas injection).

- target pressure input : this will control the water injection so that the reservoir pressure never goes under the target pressure entered.
- Voidage replacement input : this will control the water injection taking in account a voidage replacement scheme, defined by a percentage of voidage replacement entered by the user.
- Water recycling : this option enables to inject a defined percentage of the produced water
- Fixed Rate : this option enables to inject a defined rate of water.

In order to respect these constraints, the injection well needs to be set as controllable.
To do so, select **Main** what will enable you to come back to **GAP** main window. Go in the water injection model window, right click on the well and select **Controllable**. A red circle will appear around the well which confirms that the well can be choked back by the software.

Come back into the prediction run by using again the icon : then set a fixed water injection rate of 3000 STB / d.

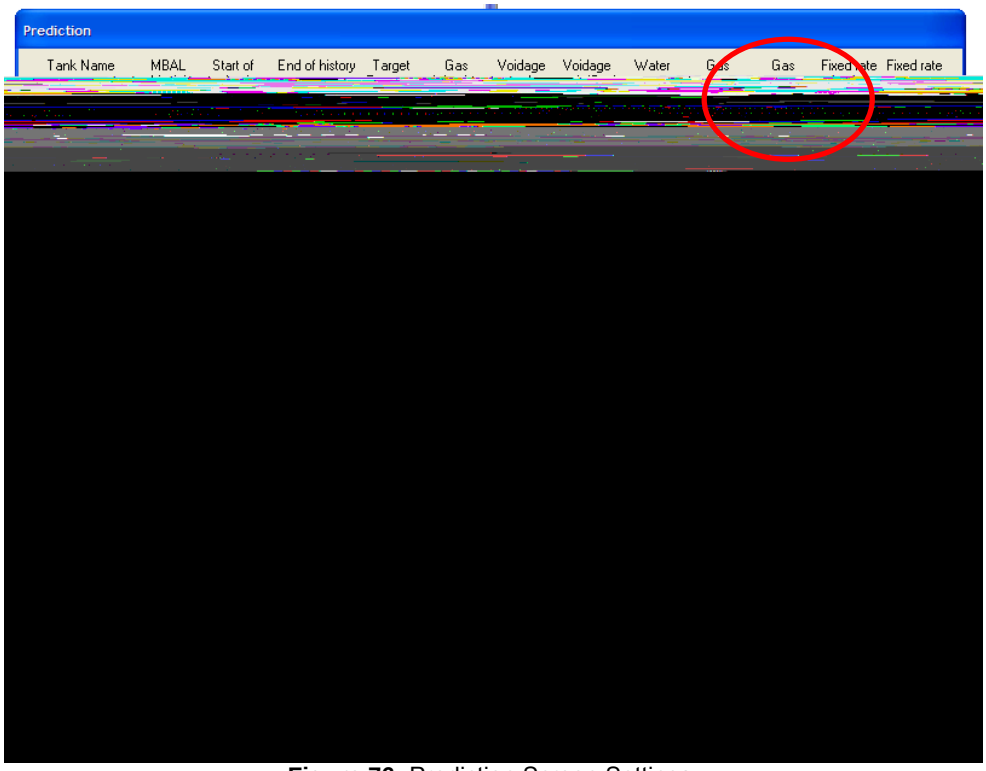


Figure 76: Prediction Screen Settings

Click **Next** to go to the next prediction screen : It summarises the input data for the tank chosen.

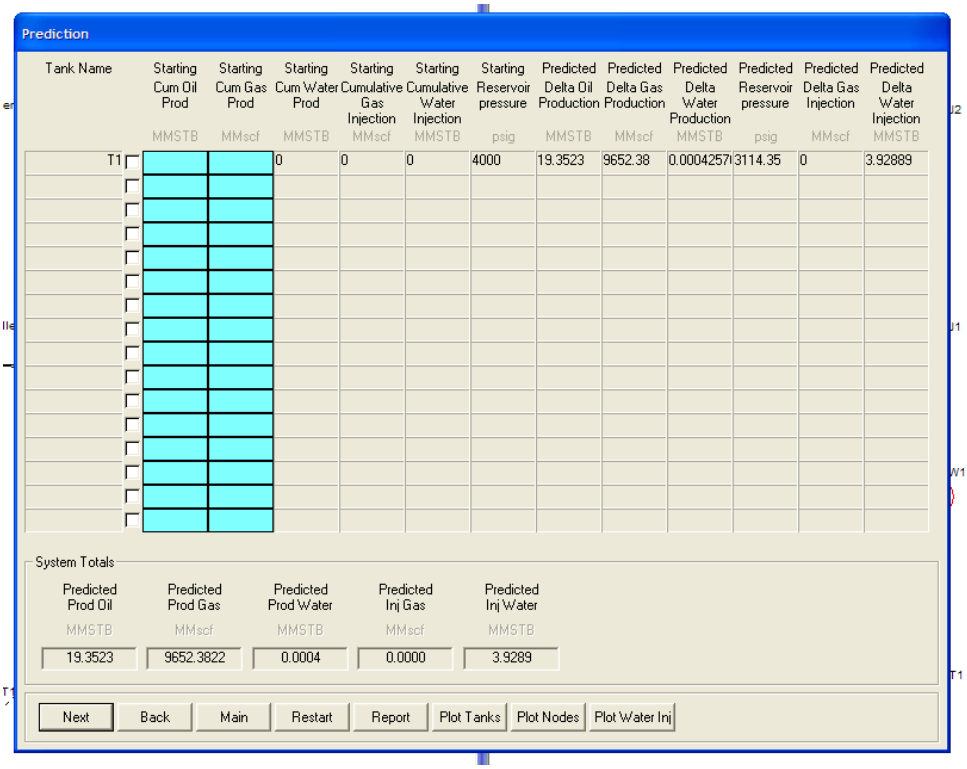


Figure 77: Prediction Screen

Select **Next** and allocate the amount of gas available for gas lift purposes.

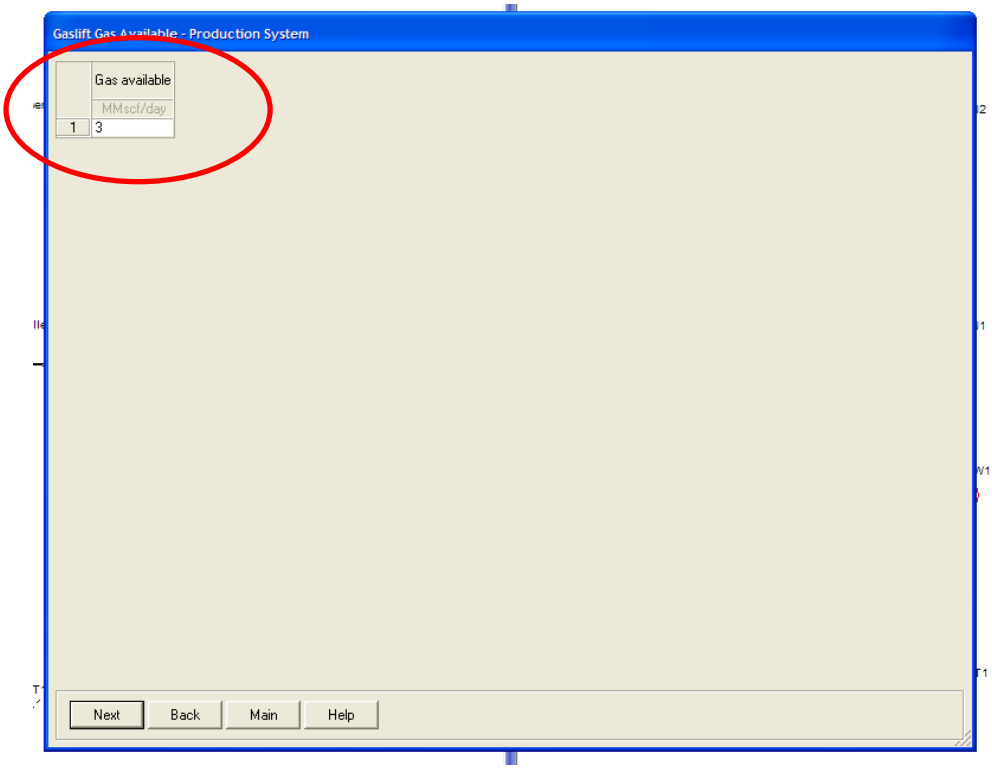


Figure 78: Gas Lift Gas Allocation

Select **Next** and allocate a separator pressure of 250 psig.

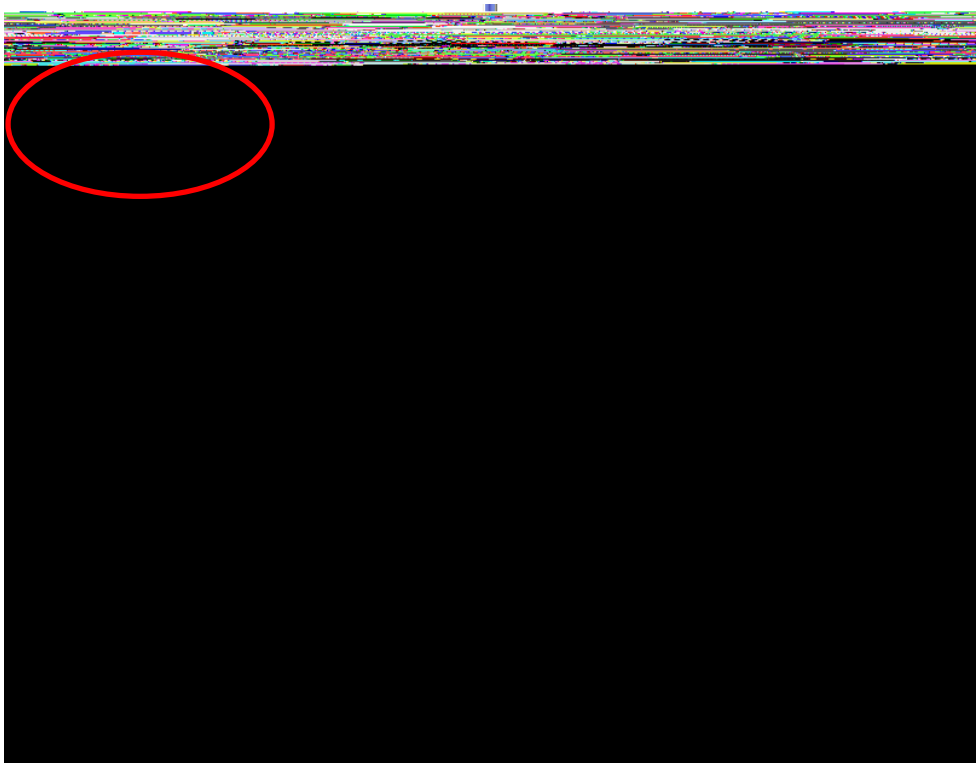


Figure 79: Separator Pressure Allocation

Select **Next** and allocate a injection manifold pressure of 2000 psig.

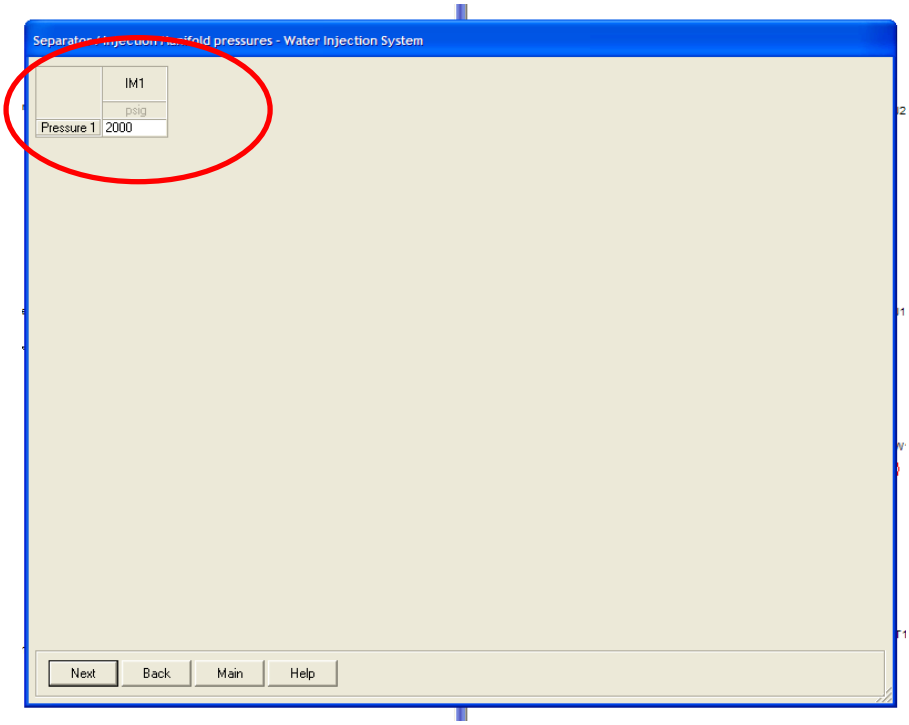


Figure 80: Water Injection Manifold Pressure Allocation

Select **Optimise and Honour Constraints** and **Calculate**. This allows the Solve Network cycle to be performed for each of the 15 time steps requested, while respecting the constraints implemented.

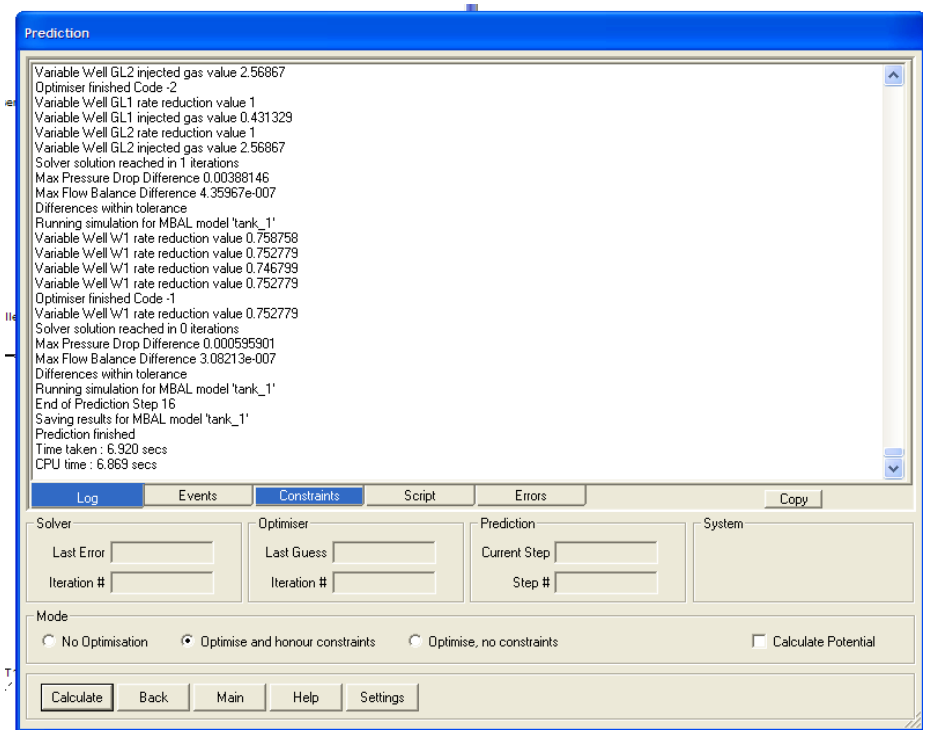


Figure 81: Material Balance Prediction Calculation Screen

As soon as the calculation is finished, select **Main** and return to the main **GAP** window.

To inspect the results, double click on the tank and select **MBAL Results**. This enables accessing the global prediction results for the tank. To check that the constraint on the water injection rate as been respected, select **Plot | Variables** and choose the variables you want to display on the plot, here **Average Water Injection Rate Vs. Time**.

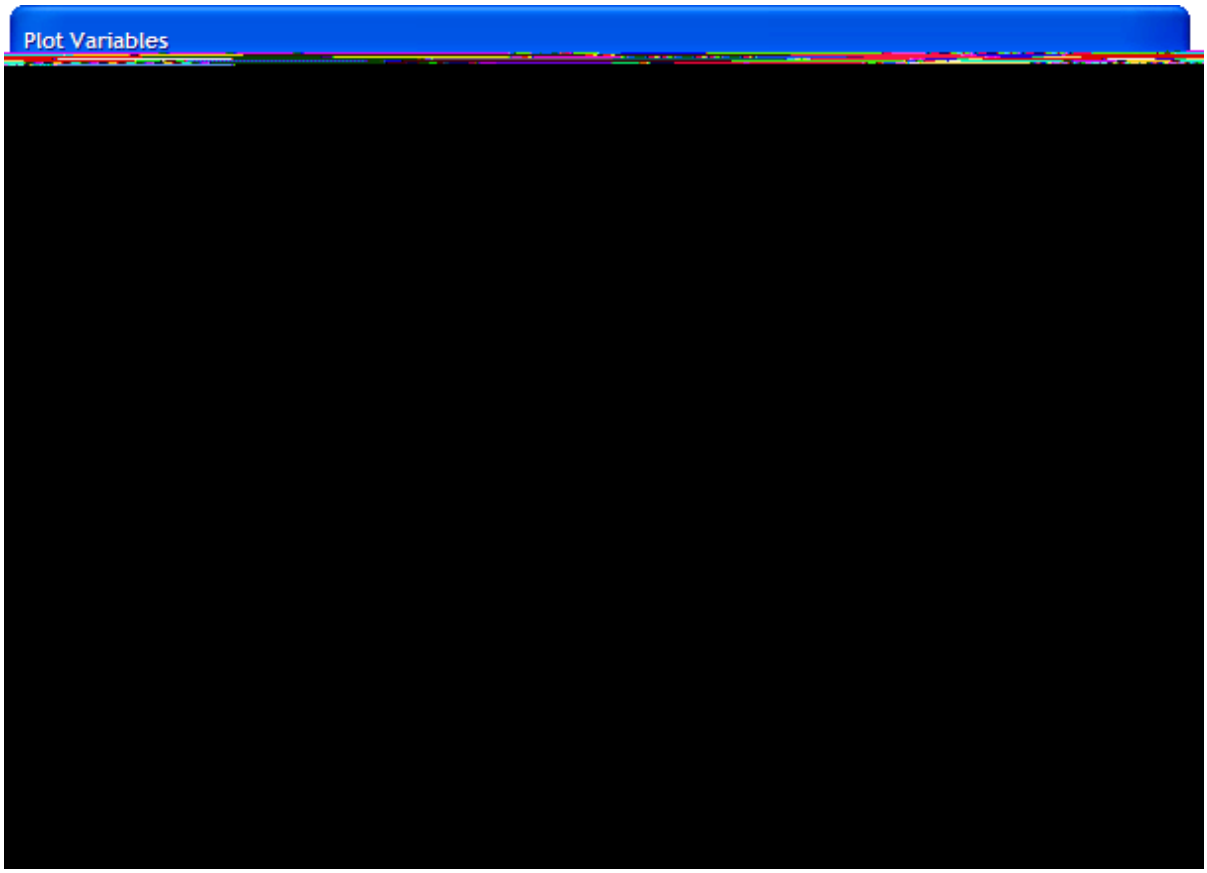


Figure 82: Selection of the Variables displayed on the Plot

Select **Done** and the plot is displayed. It is then noticeable that the constraints on the water injection rate set previously as been fulfilled.

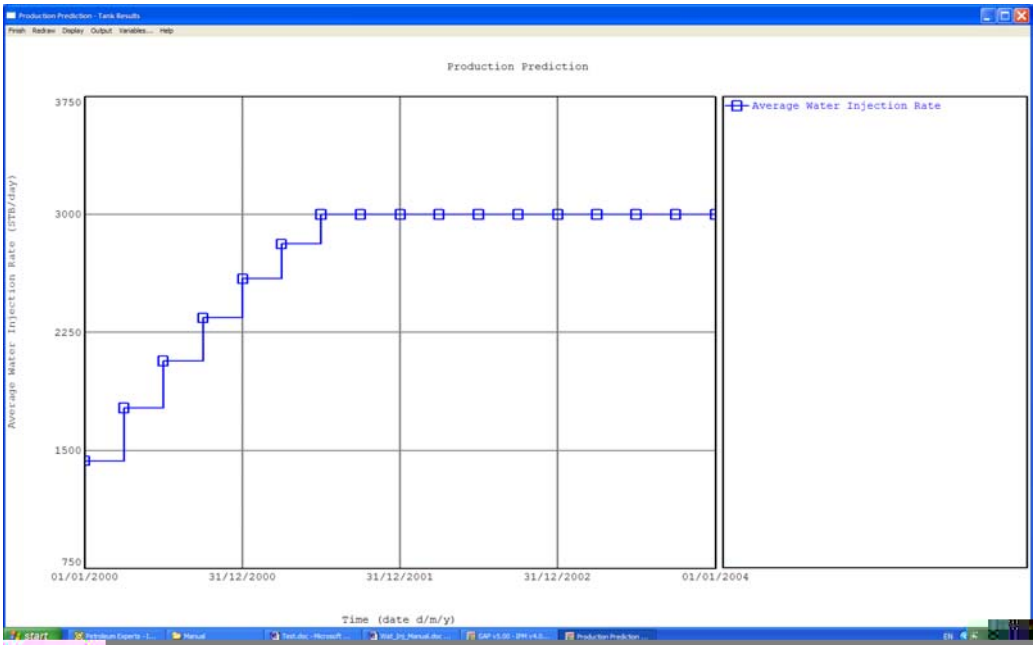


Figure 83: Average Water Injection Rate Vs. Time

2.4.8.5Associated Gas Injection Model

A similar procedure can be followed to set up **GAP** surface network model associated with a Gas Injection System, as shown on the following screenshots.

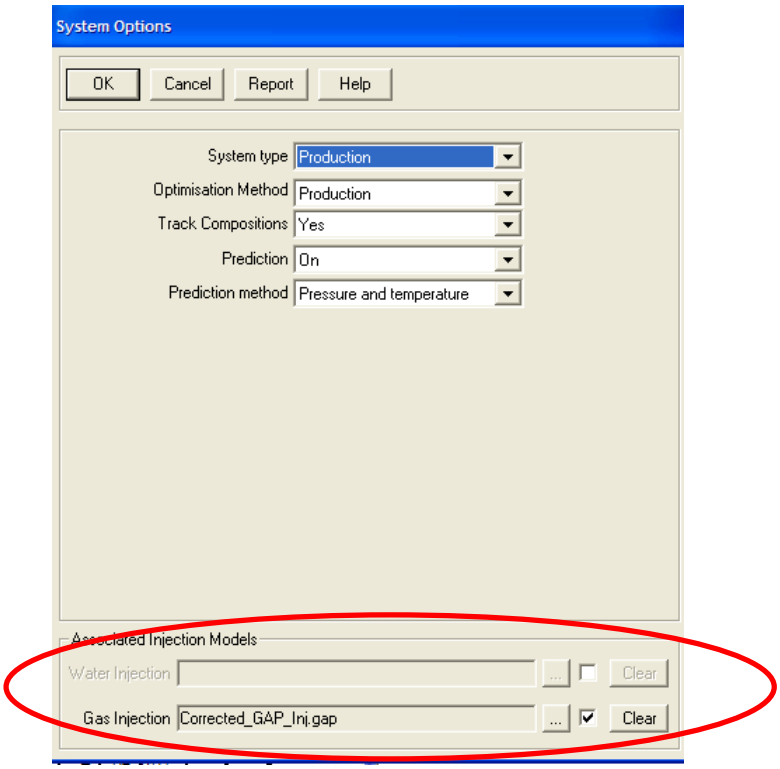


Figure 84: Associated Gas Injection Model Settings

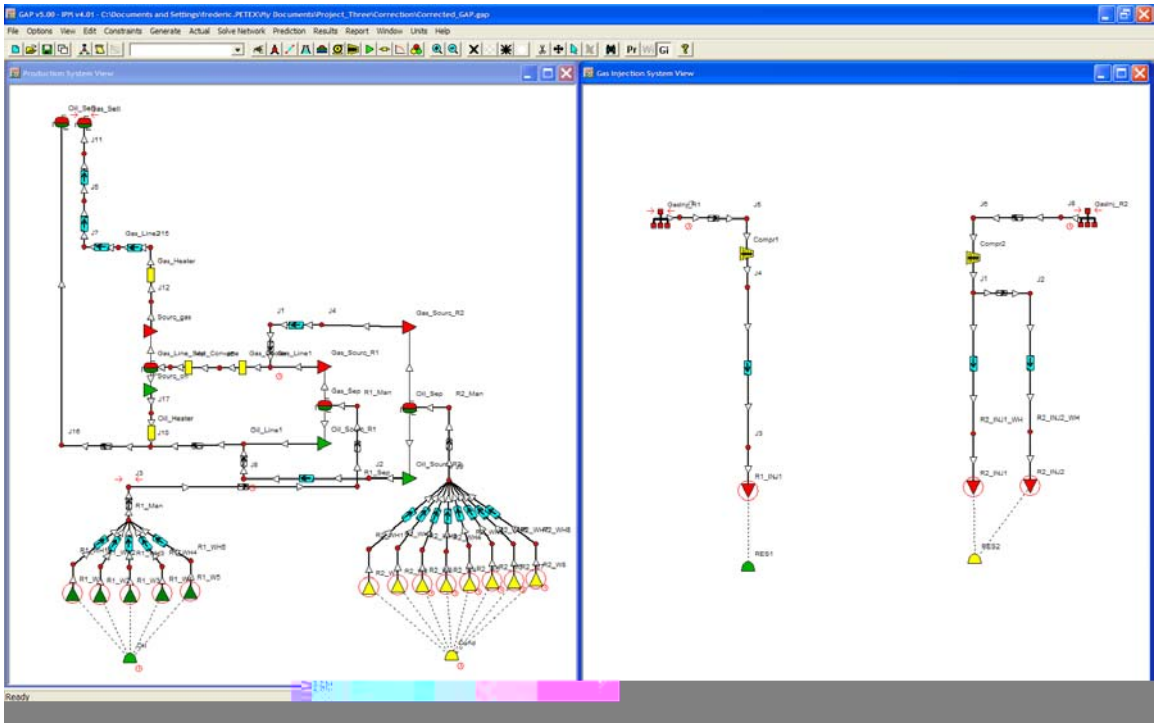


Figure 85: Associated Gas Injection Model Example

3 Physics Examples

This section contains the following tutorials:-

- **PROSPER Gas Lift Example:**
  This example builds a **PROSPER** well model including a gas lift system. It also shows how to design the gas lift system.

- **PROSPER ESP Example:**
  This example builds a **PROSPER** well model including an ESP and shows how to design the ESP.

- **MBAL Gas History Matching Example:**
  This example shows how to run the history matching section. It also includes Fw matching and verification of the water cut using the production prediction. It is a continuation of the **MBAL** gas example in the dexterity section.

- **MBAL Oil History Matching Example:**
  This example builds an **MBAL** tank model and shows how to perform the history matching.

3.1 Gas Lift Example

This example assumes that the user is already familiar with setting well models in **PROSPER**.

Objective:
In this model the objective is:

1. Quality check the test / production data that is available. This quality check is based on what is possible physically.
2. Based on the checked data, we select and build our **PVT** and flow models.
3. Design a new gas lift system for this well.
4. Use QuickLook option of **PROSPER** for performance diagnosis.

Methodology:
The single well model will be built step by step and at each step any available test / production data available will be used to validate the model. Also as we progress through the example, new test data will be added and checked against data previously entered. In case of conflicts, reasoning on what is possible physically will be used to **RESOLVE** this conflict.

Data Available:

PVT Data:

- Temperature = 250.0 deg F
- Bubble Point Pb = 2200.0 psig
- GOR at Pb = 500 scf/stb
- Oil FVF at Pb = 1.32 rb/stb
- Oil viscosity at Pb= 0.4 cp
- Oil gravity = 39.0 API
- Gas gravity = 0.798
- Water Salinity = 100,000 ppm

Gradient Data:

Data Set 1

- Well head pressure = 264.0 psig
- Water cut = 20.3 %
- Liquid rate = 6161.0 stb/day
- GOR = 432 scf/stb
- Gas Lift = 0 MMscf/day
- Injection depth = 13000 ft
- Pressure @ 14800 ft = 3382.0 psig

Data Set 2

- Well head pressure = 264.0 psig
- Water cut = 20.3 %
- Liquid rate = 1100.0 stb/day
- GOR = 500 scf/stb
- Gas Lift = 1.0 MMscf/day
- Injection depth = 8000.0 ft
- Pressure @ 1500 ft = 500.0 psig

3.1.1 Setting Up the Basic Model

We are going to set up a model with the following options:

Fluid	Oil and water
Method	Black oil
Separator	Single-stage
Emulsions	No
Hydrates	Disable warning
Water viscosity	Use default correlation
Flow type	Tubing flow
Well type	Producer
Artificial lift method	Gas lift
Type	No friction loss in annulus
Predict	Pressure and temperature (offshore)
Model	Rough approximation
Range	Full system
Output	Show calculating data
Well completion type	Cased hole
Gravel pack	No
Inflow type	Single branch
Gas coning	No

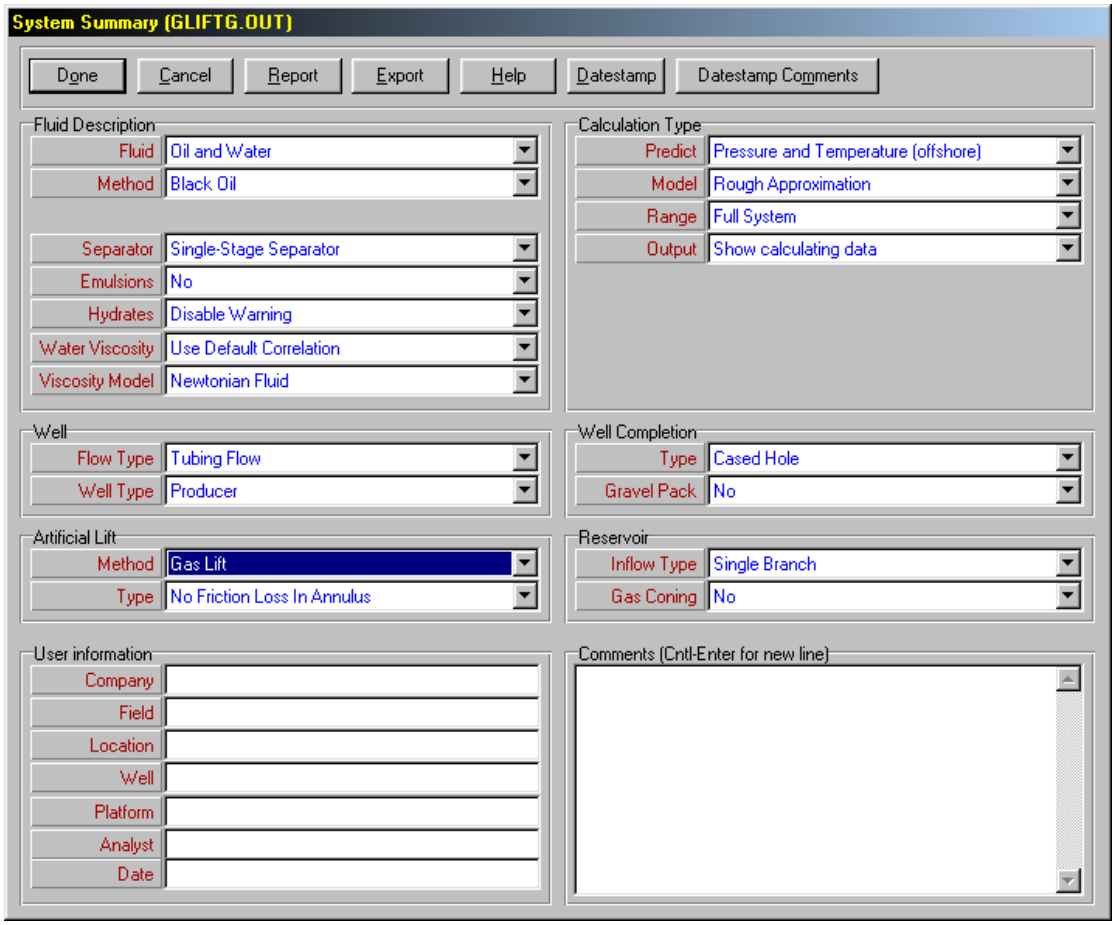


Figure 66: Setting up the options

Select the Option menu in **PROSPER** and select the following options:

Then select **| PVT | Input Data** and enter the following data:

Solution GOR	500 scf/stb
Oil gravity	39 API
Gas gravity	0.798
Water salinity	100000 ppm
(no impurities no gas)	

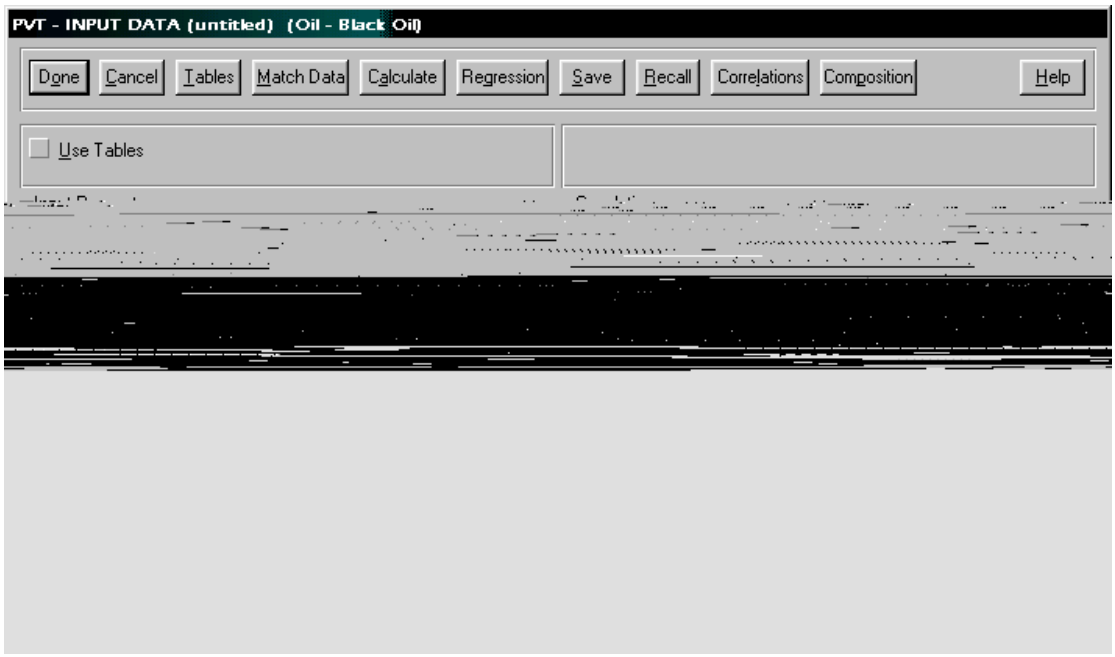


Figure 67: Entering **PVT** parameter

Click the **Match Data** button on the above dialog and enter the **PVT** match data that we have:

Temperature	250 degree F
Bubble point	2200 psig
GOR @ bubble point	500 scf/stb
Oil FVF @ bubble point	1.32 rb/stb
Oil viscosity @ bubble point	0.4 cp

Figure 68: Entering **PVT** lab data

Click **Done** on the above dialog to go back to the **PVT** input dialog. Then perform the match calculation by clicking the **Regression** button and then the **Match All** button.

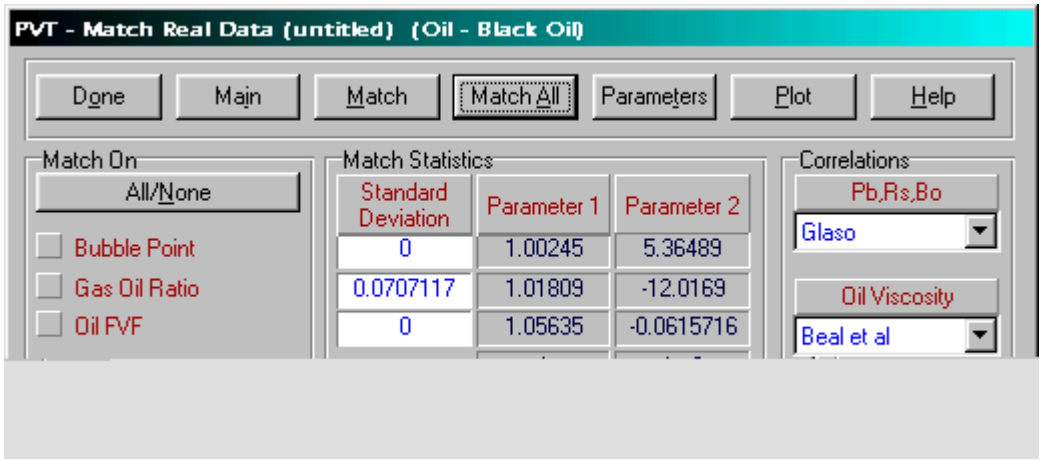


Figure 69: **PVT** matching

After finishing the **PVT** match, click the **Parameters** button to view the statistics and select the best correlation for **PVT** modeling. Based on the theses regression parameters (parameter 1, which is multiplier and parameter 2 which is a shift factor) and standard deviation, select the best model. Ideally the std deviation should be very small, parameter 1 should equal 1.0 and parameter 2 should equal zero.

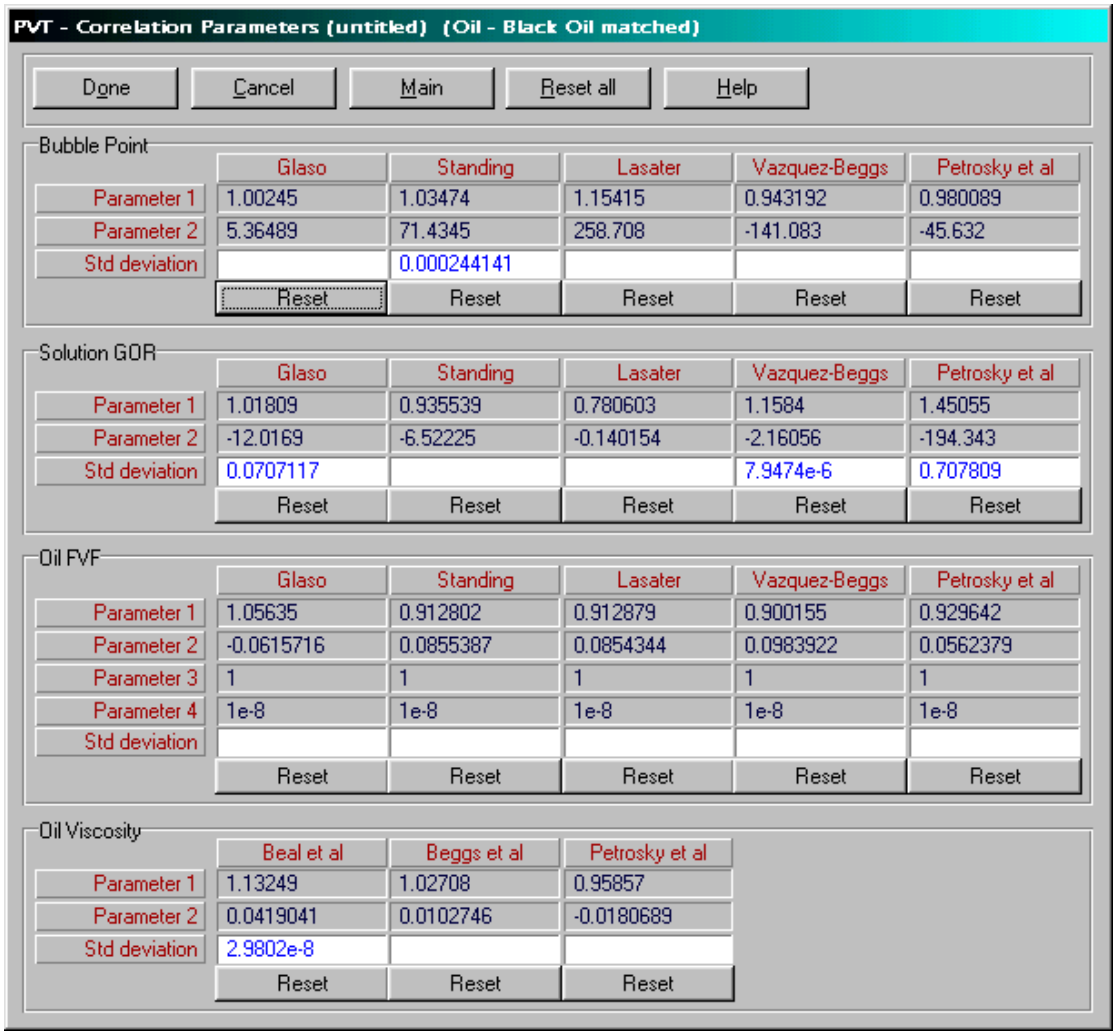


Figure 70: Matching parameters

Based on the results, we might want to use the Beggs et al correlation for viscosity modelling and Glaso for all other properties. Click on **| Done | Done** to go back to the main ***PVT*** screen. Select the correlations to use in the main ***PVT*** screen.

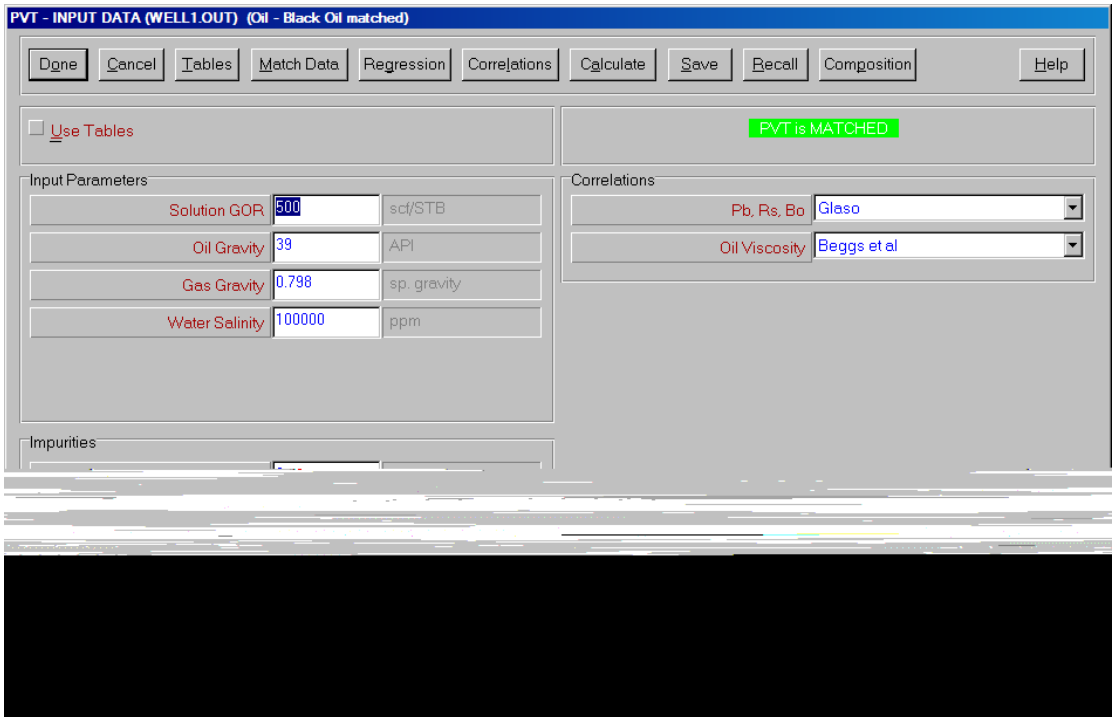


Figure 71: Select the correlation used

Once this is done, click the **Done** button to return to the main window.

Now click on the | **System | Equipment (Tubing etc.)** menu option and input the equipment data:

Deviation Survey

It is given the deviation survey as follow:

Measured depth (ft)	True vertical depth (ft)
0	0
1000	1000
2500	2405
6500	5322
15200	11500

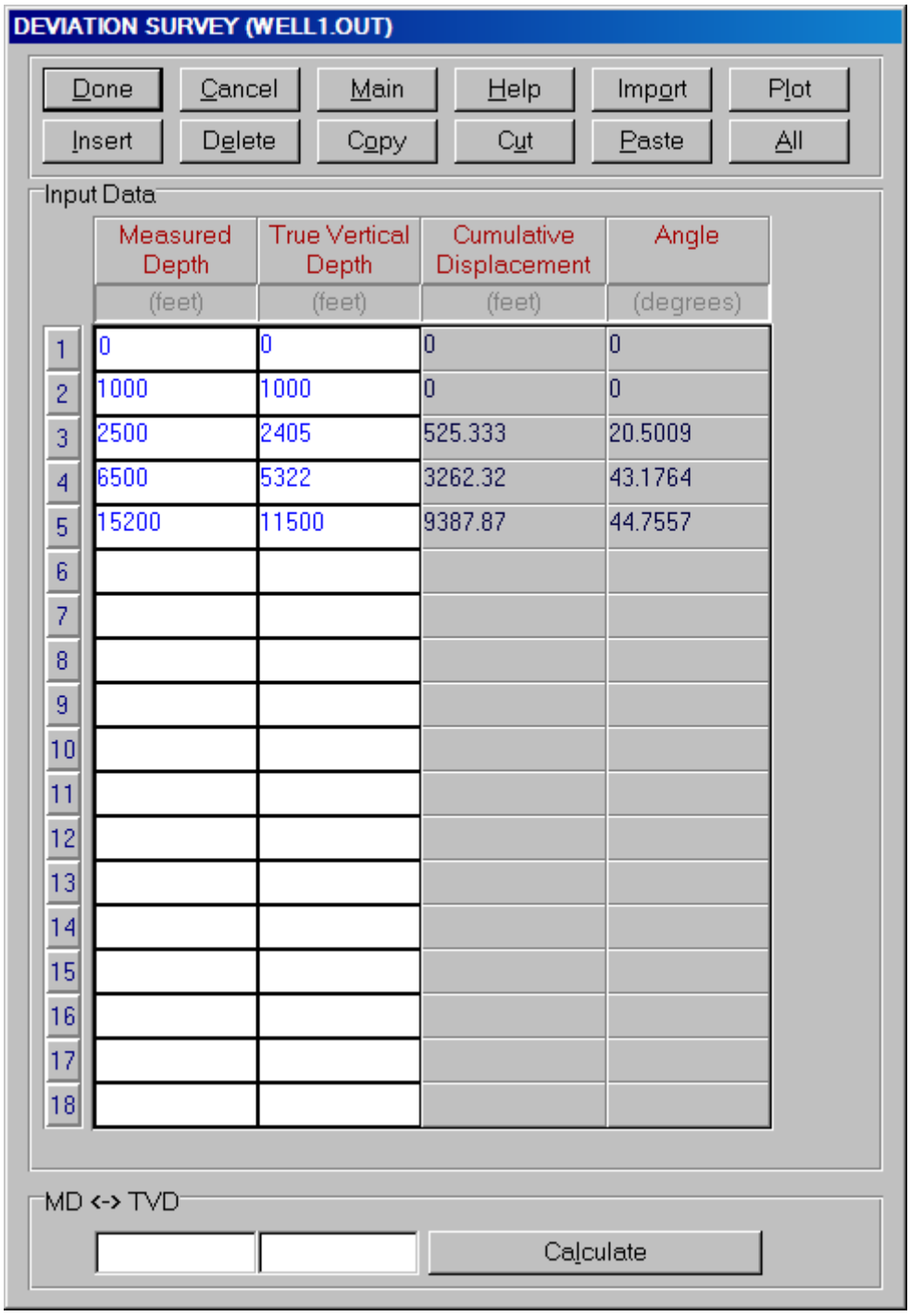


Figure 72: Deviation survey

Down hole Equipment

It is given the down hole equipment as follow:

Type	Measured depth (ft)	Internal diameter (in)	Roughness (in)
X'mass tree	0		
Tubing	14500	3.96	0.0006
Casing	15200	6.00	0.0006

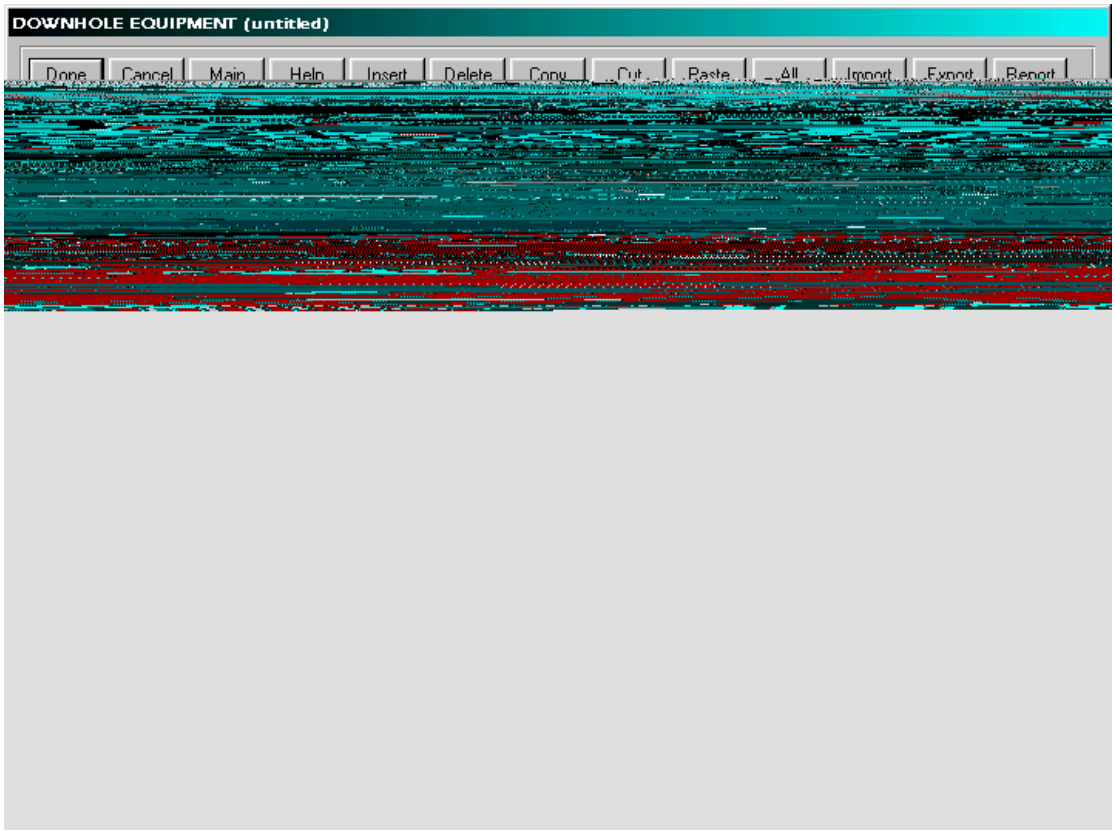


Figure 73: Downhole equipment

Geothermal Gradient

It is given the Geothermal gradient as follow:

Measured depth (ft)	Formation temperature (degree F)
0	50
15200	250

Overall heat transfer coefficient 8 BTU/hr/ft2/F

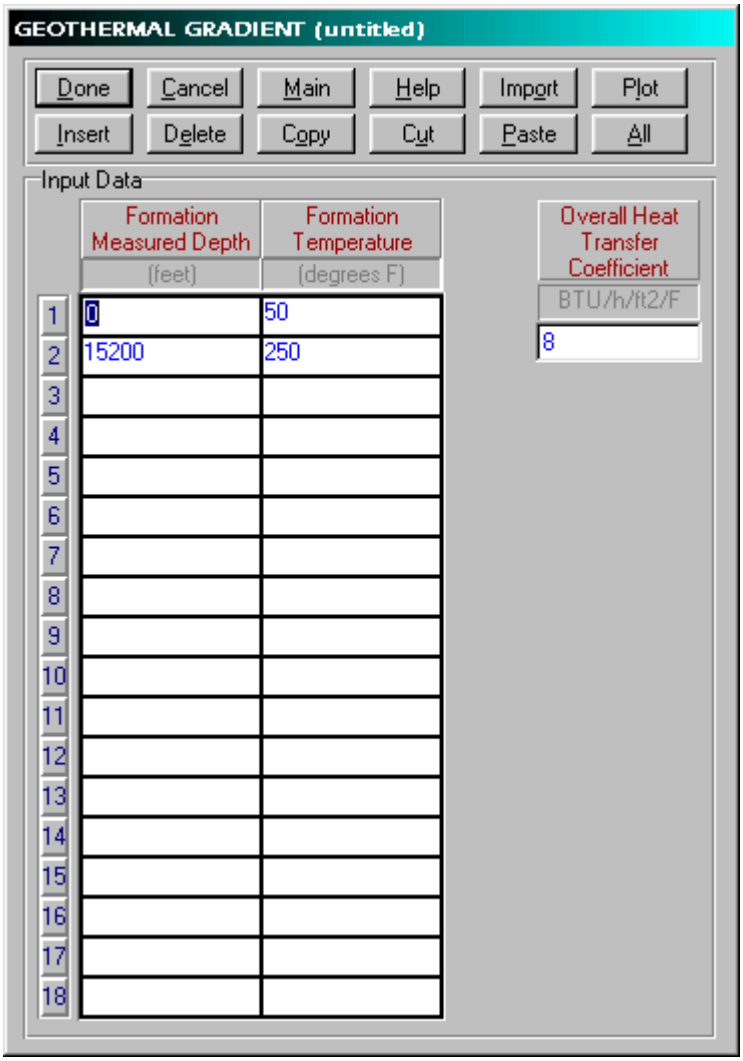


Figure 74: Geothermal gradient

Note: There is no surface equipment. Hence we can leave the surface equipment section alone. Also, leave the heat capacities to the default values. Click on **| Done** to exit to the main screen.

Next click on **System | Inflow Performance** and select the IPR model and enter the basic parameters:

Reservoir model	Darcy
Mechanical / Geometrical skin	Enter by hand
Reservoir pressure	3844 psig
Reservoir temperature	250 degree F
Water cut	20.3 %
Total GOR	500
Relative permeability	No

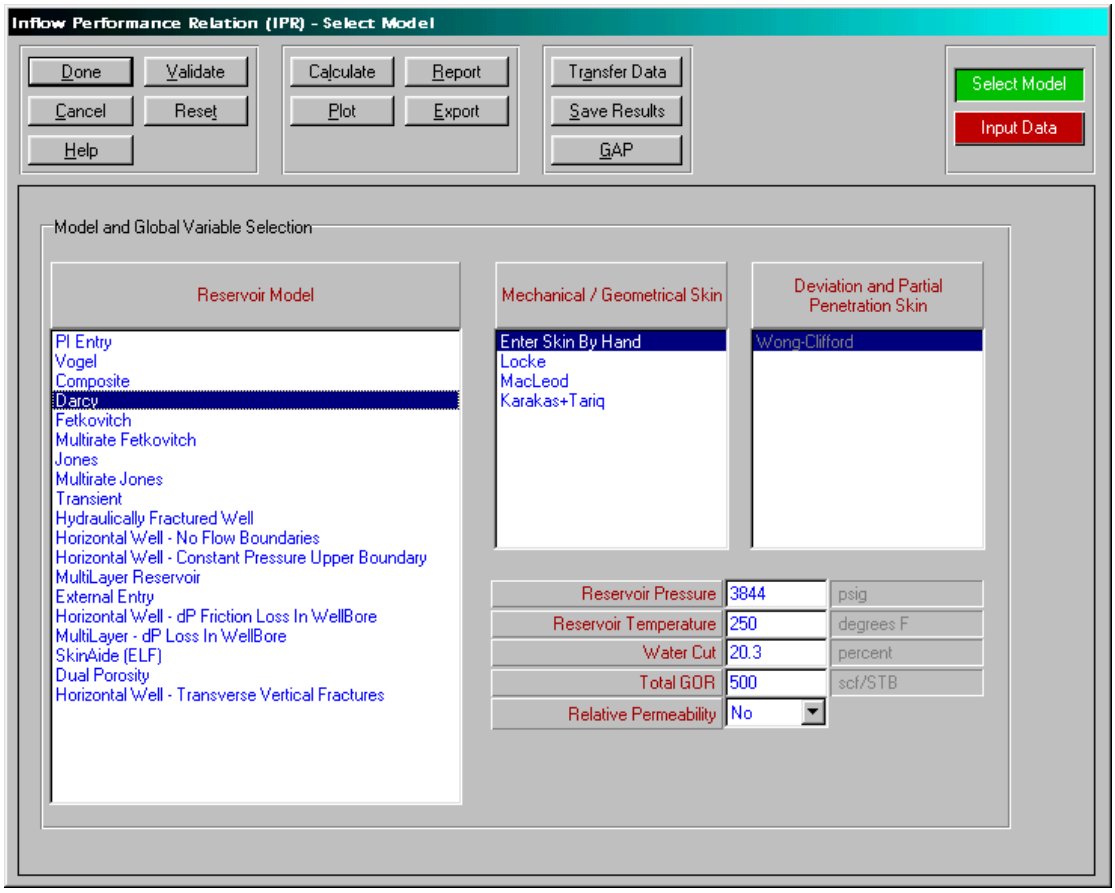


Figure 75: Select reservoir model

Then enter the IPR data as follow:

Reservoir Permeability	100 md
Reservoir thickness	100 ft
Drainage area	100 acres
Dietz shape factor	31.6
Well bore radius	0.354 ft

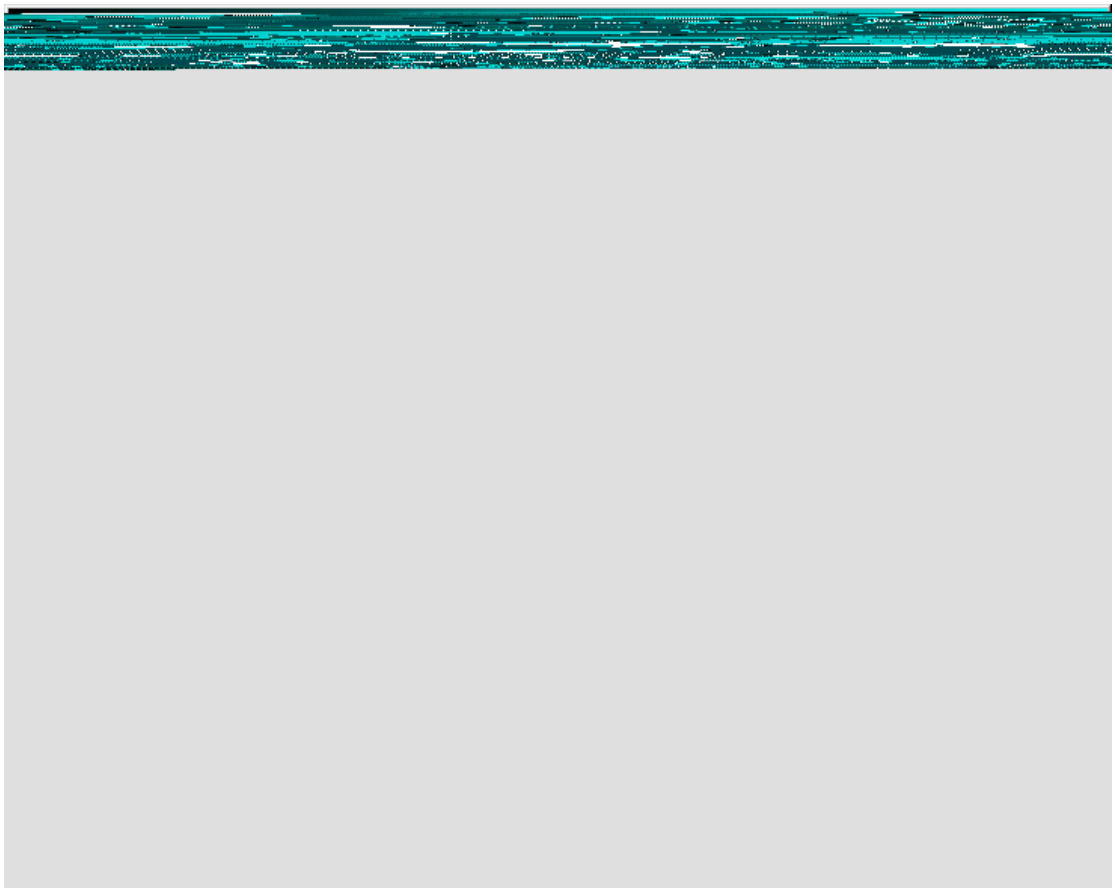


Figure 76: Entering parameters for the reservoir model

Click on the tab labelled ‘Mech/Geom Skin’ and a screen prompting for a skin value will occur. Enter a skin of 0.

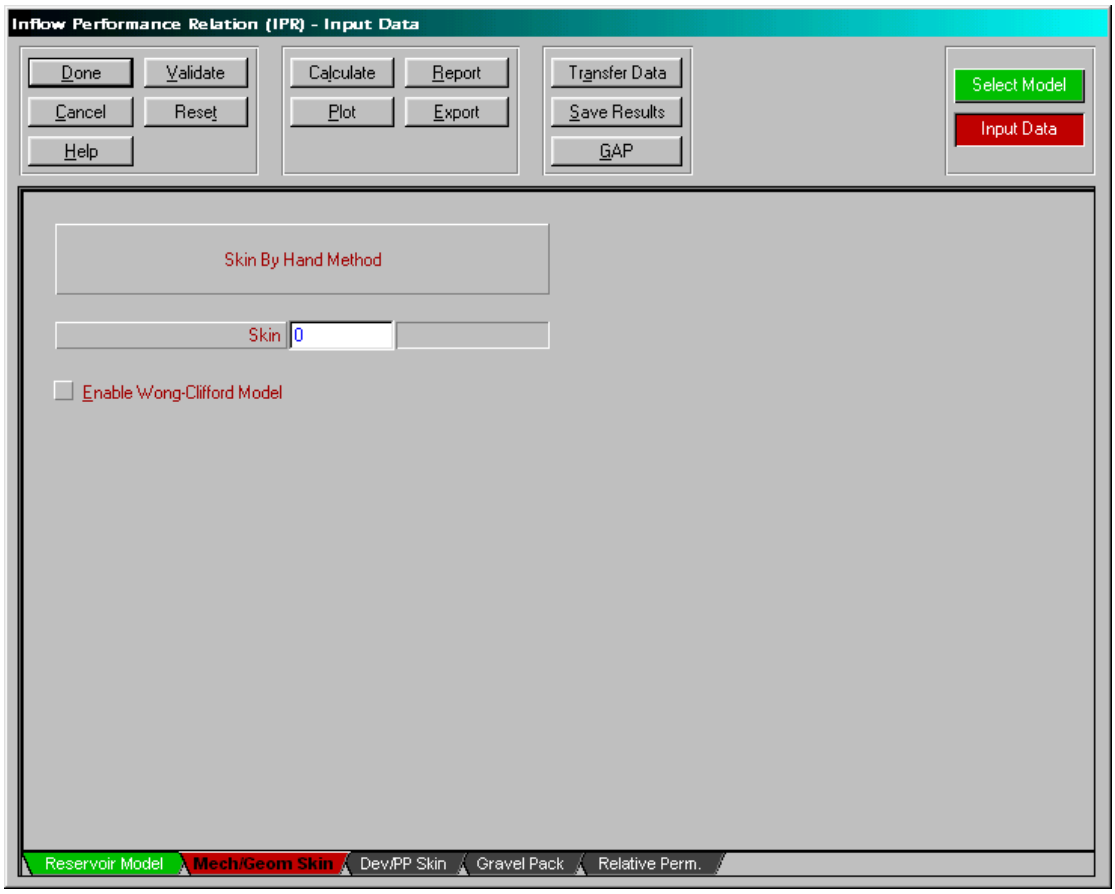


Figure 77: Entering skin

Click on the **Calculate** button to get the following IPR plot:

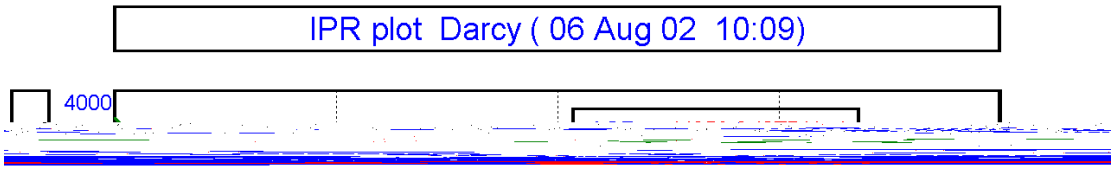


Figure 78: IPR plot

Click the **Main** menu item on the IPR plot in order to get back to the main ***PROSPER*** window. Next click on the **System | Gaslift Data** menu item and enter the gas lift data as follows.

Gaslift gas gravity	0.7
Mole percent H2S	0%
Mole percent H2S	0%
Mole percent H2S	0%
GLR injected	0 scf/stb
Gas lift method	Optimum Depth of injection
Maximum Depth of injection	13000 ft
Casing pressure	1900 psig
DP across valve	100 psi

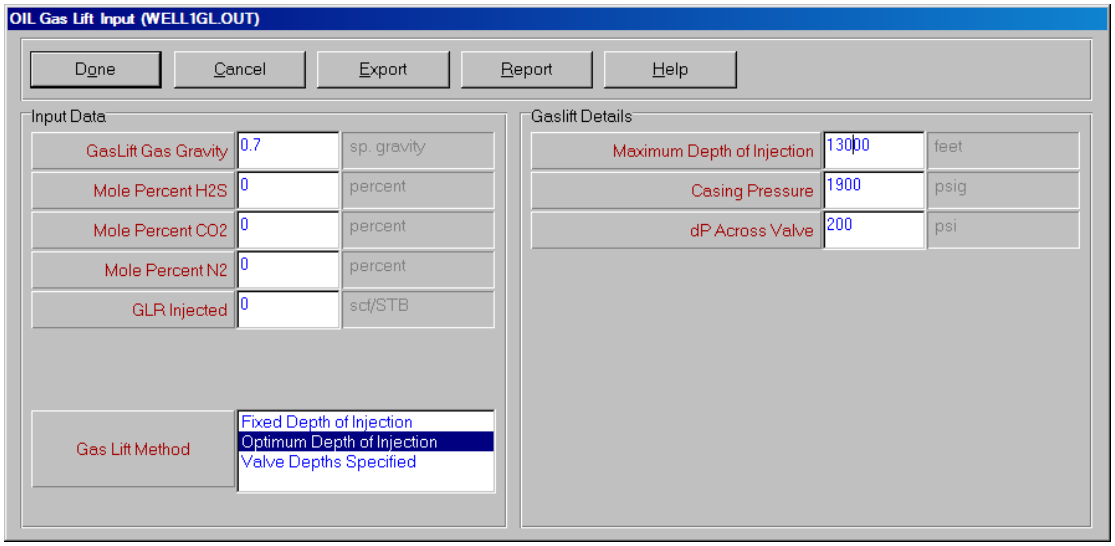


Figure 79: Gaslift specification

We have selected an optimum depth of injection, but want to limit the injection depth to 13000 feet, which is our packer depth. Also we know that we will have gas lift gas available at 1900 psig at casing head. Click on **Done** to complete this and to go back to the main **PROSPER** screen.

We should now save the file. For this we click on **| File | Save As**, and name the file as GLIFTG.OUT for instance in your working directory.

3.1.2 Matching Test Data and Data Quality Check Methods

The first thing that we will do is to quality check our data. Let us try to use data set one as defined at the start of the tutorial. The first step would be to check on Data Set 1. For this, Select the **Matching | Correlation Comparison | Tubing** menu option and enter the following data, selecting correlations as highlighted:

Well head pressure	264.0 psig
Water cut	20.3 %
Liquid rate	6161.0 stb/day
GOR	432 scf/stb
GOR free	0 scf/stb
Gas Lift gas rate	0 MMscf/day
Injection depth	13000. ft
Pressure @ 14800 ft	3382.0 psig
Correlations	Duns and Ros Modified
	Hagedorn Brown
	Fancher Brown
	Petroleum Experts 2
	Petroleum Experts 3

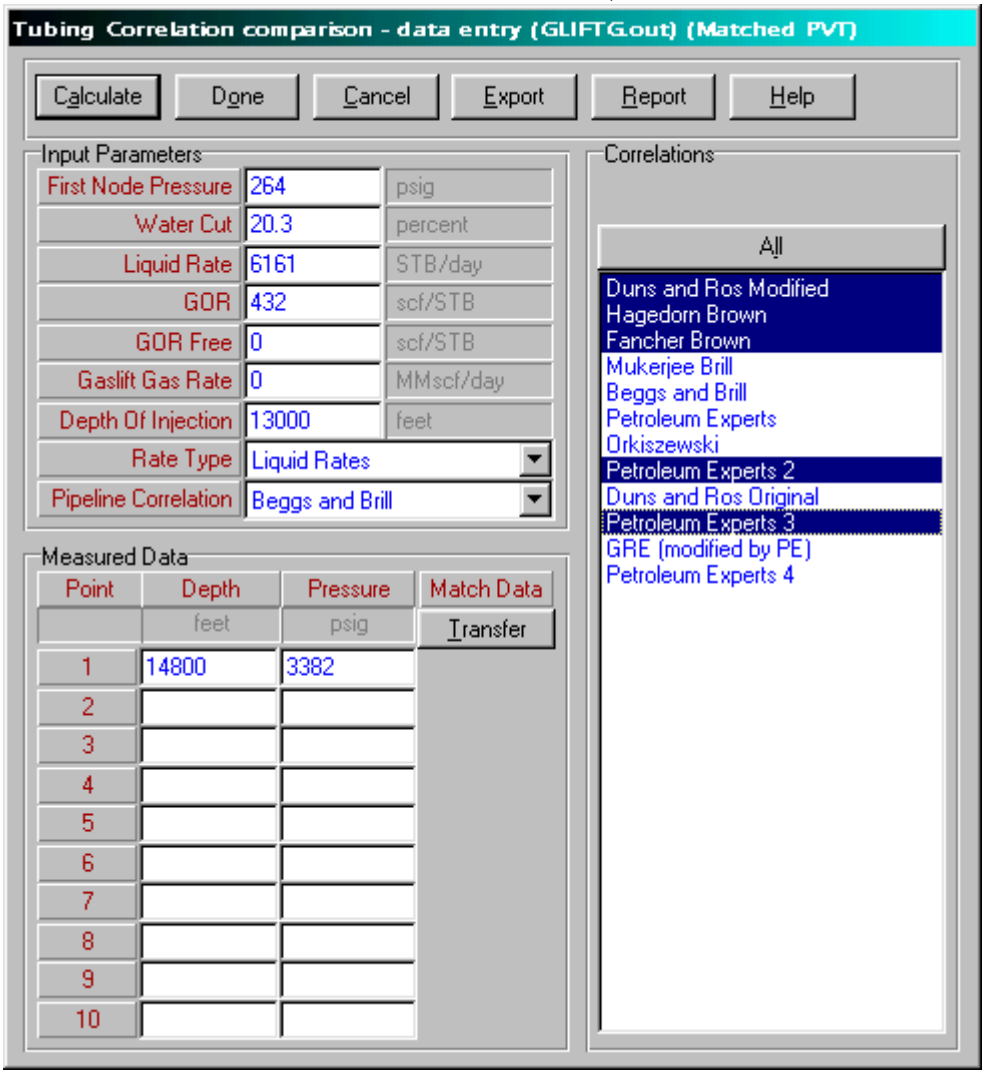


Figure 80: Correlation comparison

Then click the **Calculate** button and the **Calculate** button again on the next dialog. Once we perform the calculations and plot the results, we get the following plot:

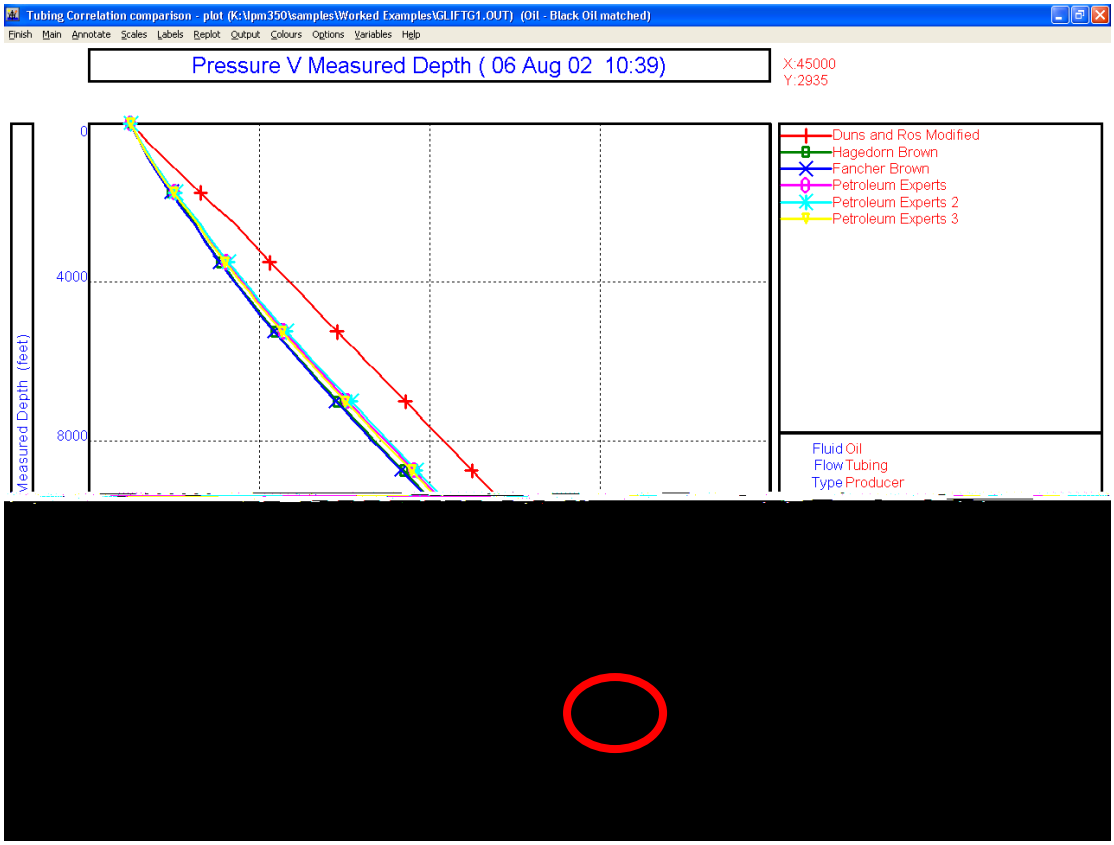


Figure 81: Correlation comparison plot

If we notice the bottom right hand corner of the plot, the test data point lies to the left of the pressure traverse generated by the Fancher Brown correlation.

But the Fancher Brown correlation is a non-slip correlation, so it predicts least pressure drops. However the plot indicates that our test point requires lesser pressure drops than Fancher Brown so there is obviously something wrong. This means that the **PVT** model we have and the test data are in conflict. If we look at the test data itself, we can see that we are reporting a GOR of 432 scf/stb at a reservoir pressure of 3844 psig, whereas the solution GOR is 500 scf/stb and the bubble point is 2200 psig. One of the items of data is incorrect. However in this case we know the **PVT** data are correct so the reported GOR must be wrong. Hence we change the GOR and redo the calculation.

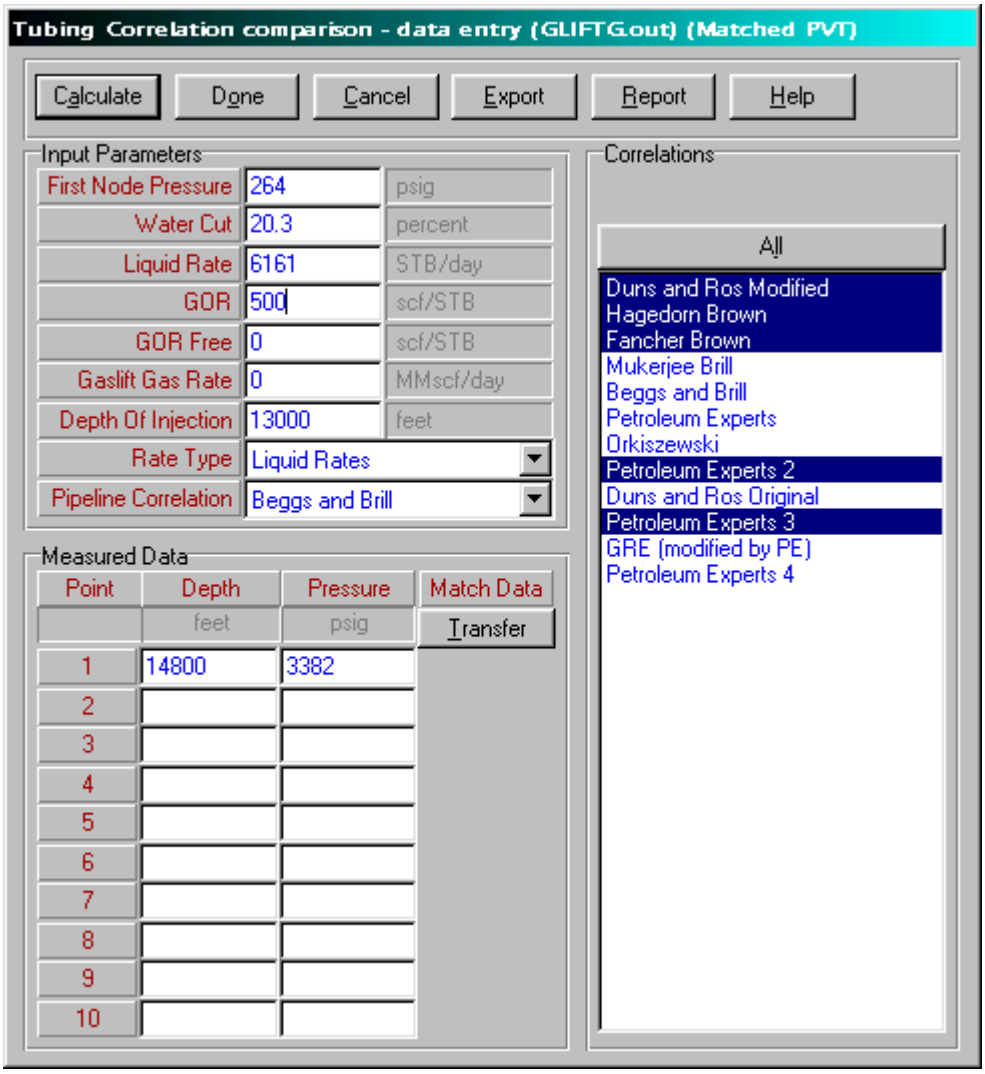


Figure 82: Change GOR

We will see the following results

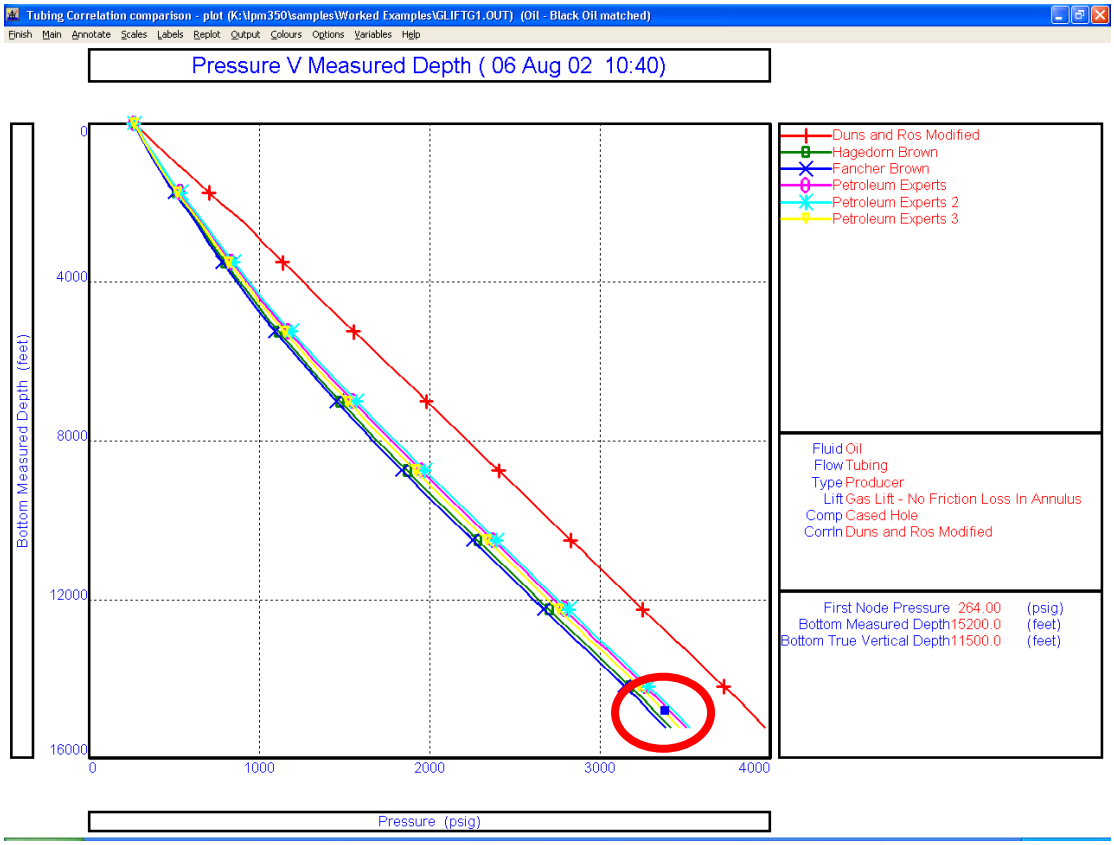


Figure 83: Results of Changing GOR

Once this change is made, the test data point does fall on the right of the Fancher Brown correlation, and we can proceed with the use of this test data.

The next step in building the model will be matching a correlation to the test data that we have and then use the matched correlation in the analysis. We will try to use data point two for this purpose – as defined at the start of this example.

If we use data point two in a similar way to data point one in the Correlation Comparison dialog, and perform the correlation comparison calculation, we can check how this test data point compares to the standard correlations. The plots are:

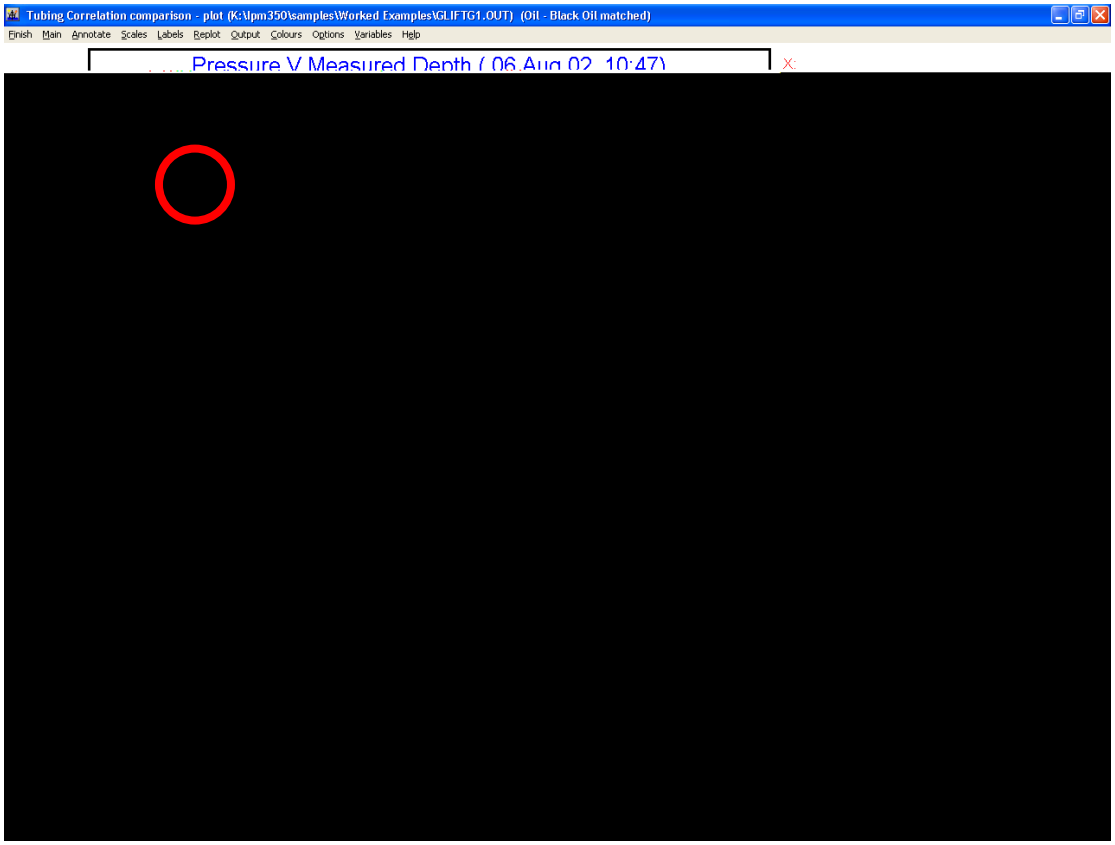

Tubing Correlation comparison - plot (K:\lpm350\samples\Worked Examples\GLIFTG1.OUT) (Oil - Black Oil matched)
Finish Main Annotate Scales Labels Replot Output Colours Options Variables Help
Pressure V Measured Depth (06 Aug 02 10:47)

Figure 84: Results of Data point 2

The test data point lies to the right of the Duns and Ross Modified (DRM) correlation. Like Fancher Brown (FB), the DRM correlation represents the other extreme of the pressure drop i.e. maximum pressure loses. Thus if a point lies to the right of the DRM, we are expecting pressure drops greater than DRM. The other point to note is that for the same well head pressure and IPR, with gas lift we are getting lower flow rates than without gas lift as indicated by data point one. It could be that the data point is wrong or the **PVT** data are incorrect. However we already know that our **PVT** data are correct, so the data point must be incorrect.

Since we already have another test data point (Data set 1) we will match the correlations to that data point. The matching process consists in reproducing the test data point by matching the two components of pressure drop i.e. gravity and friction by using multipliers (parameter 1 and parameter 2) for each correlation. The correlation that matches best will selected to model flow in the tubing. Select the **Matching | Matching | IPR/VLP (Quality Check)** and enter test data point 1 in the screen as shown below:

Well head pressure	264.0 psig
Tubing head temperature	132.8 degree F
Water cut	20.3 %
Liquid rate	6161.0 stb/day
GOR	500 scf/stb
GOR free	0 scf/stb
Gas Lift gas rate	0 MMscf/day
Injection depth	13000. ft
Pressure @ 14800 ft	3382.0 psig

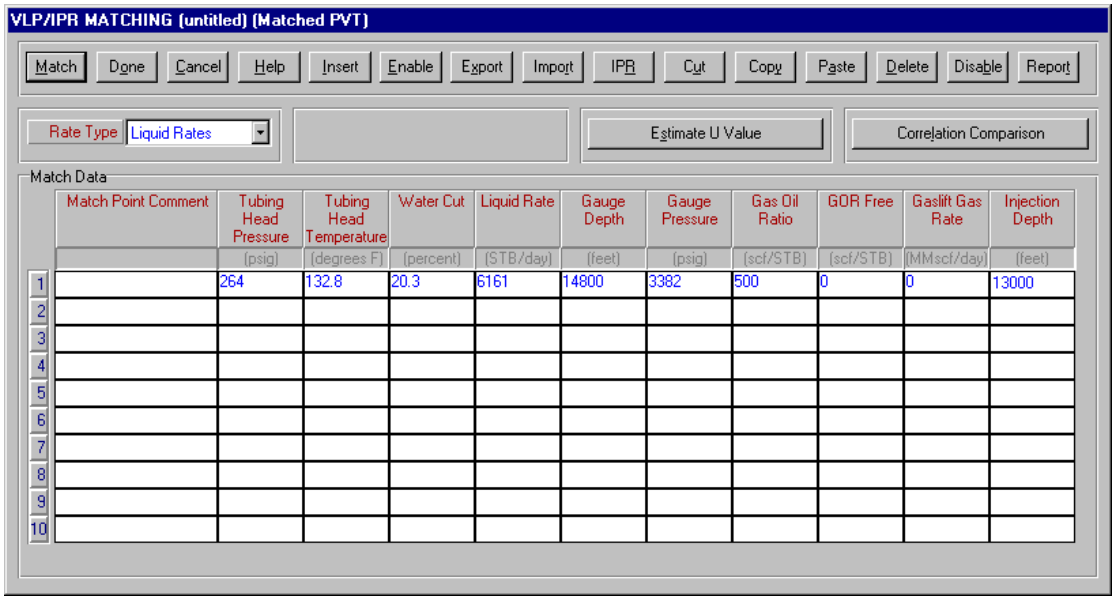


Figure 85: Entering the match data

Then click the **Match** button and select the following correlations on the next dialog:

- Hagerdorn Brown
- *Petroleum Experts* 2
- *Petroleum Experts* 3

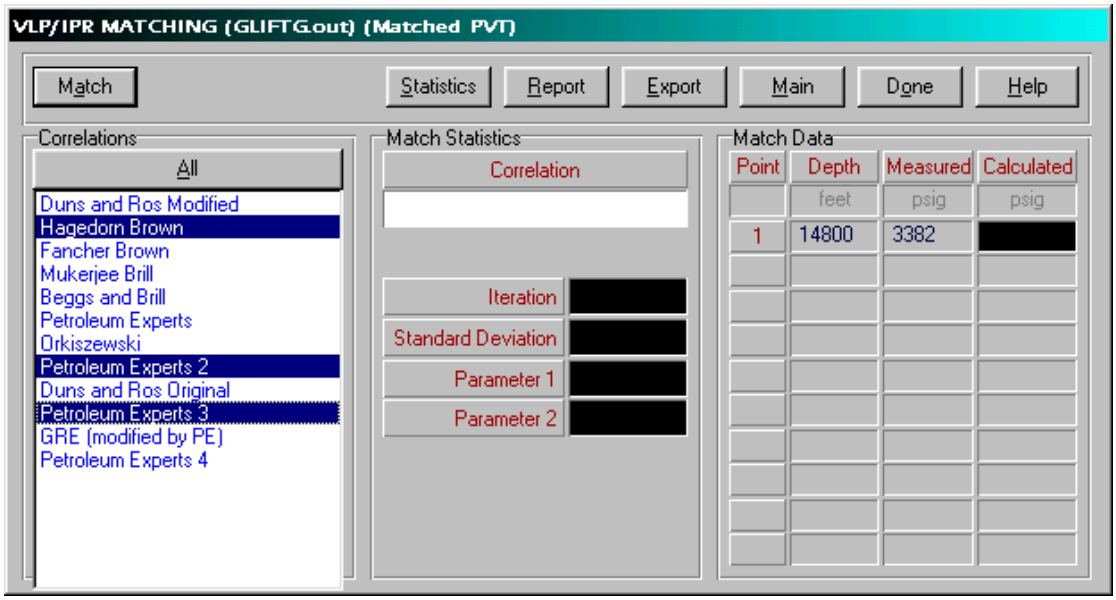
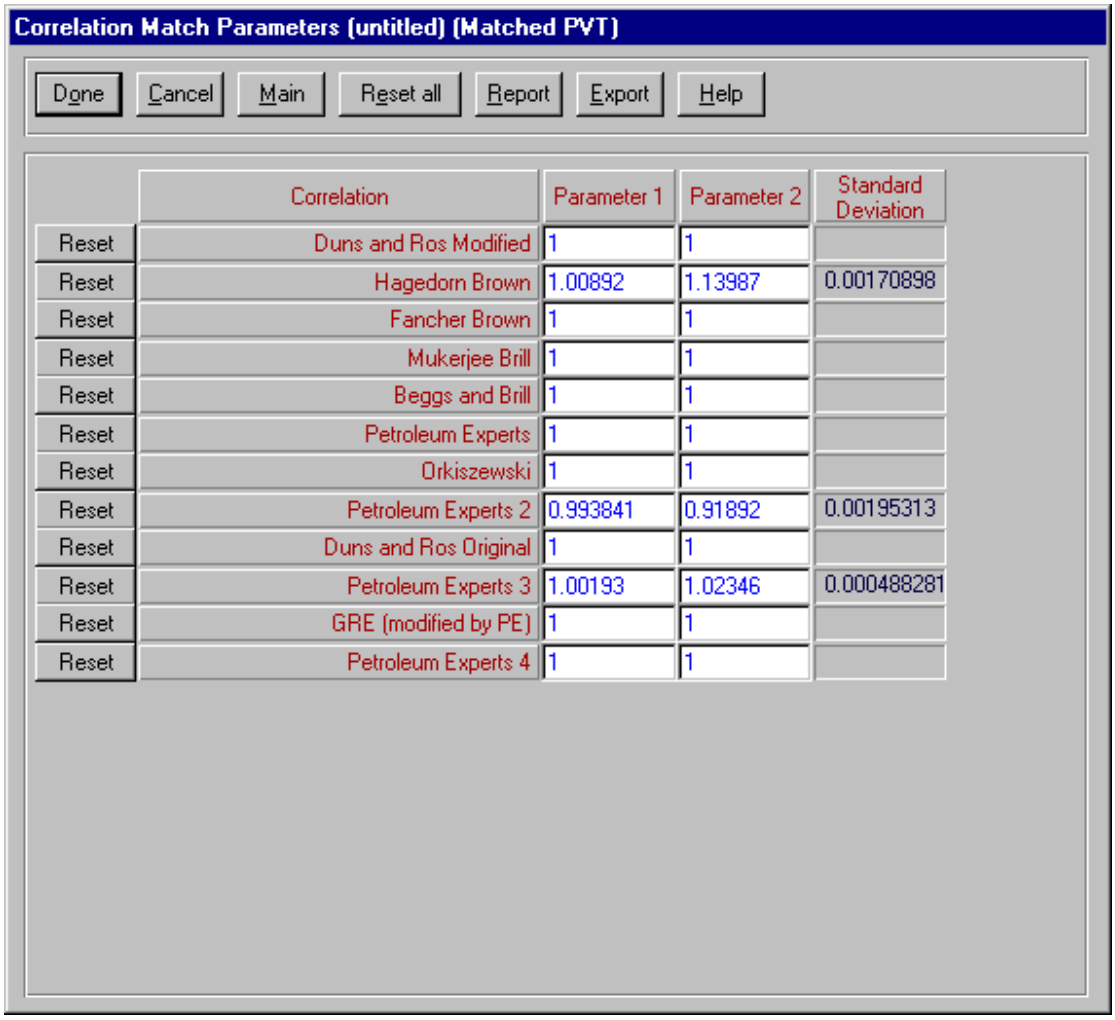


Figure 86: Selecting correlations to match

Then click on **Match** button to perform the matching calculation. Once we have performed the match calculations, the new match parameters (seen by pressing the button **Statistics**) are:



	Correlation	Parameter 1	Parameter 2	Standard Deviation
Reset	Duns and Ros Modified	1	1	
Reset	Hagedorn Brown	1.00892	1.13987	0.00170898
Reset	Fancher Brown	1	1	
Reset	Mukerjee Brill	1	1	
Reset	Beggs and Brill	1	1	
Reset	Petroleum Experts	1	1	
Reset	Orkiszewski	1	1	
Reset	Petroleum Experts 2	0.993841	0.91892	0.00195313
Reset	Duns and Ros Original	1	1	
Reset	Petroleum Experts 3	1.00193	1.02346	0.000488281
Reset	GRE (modified by PE)	1	1	
Reset	Petroleum Experts 4	1	1	

Figure 87: Matched parameters

We will use *Petroleum Experts* 2 as the vertical lift correlation.

We have now matched VLP to the test data. We should next look at the IPR. We must make sure that the IPR can supply the rate that we are getting. We can first use the tuned VLP correlation to calculate the bottomhole flowing pressure for the same conditions as the test data (same rate, water cut, GOR, well head pressure, etc.). Since IPR is a plot of bottom hole flowing pressure vs. liquid rate, we have a test point on the IPR now, which is the test liquid rate vs. the calculated bottomhole flowing pressure using the tuned VLP correlation.

All these can be done in the VLP/IPR matching section. From the correlation matched parameters screen, click on **| Done | Done**, you will go back to the VLP/IPR matching main screen. From there click on the button '**IPR**'.

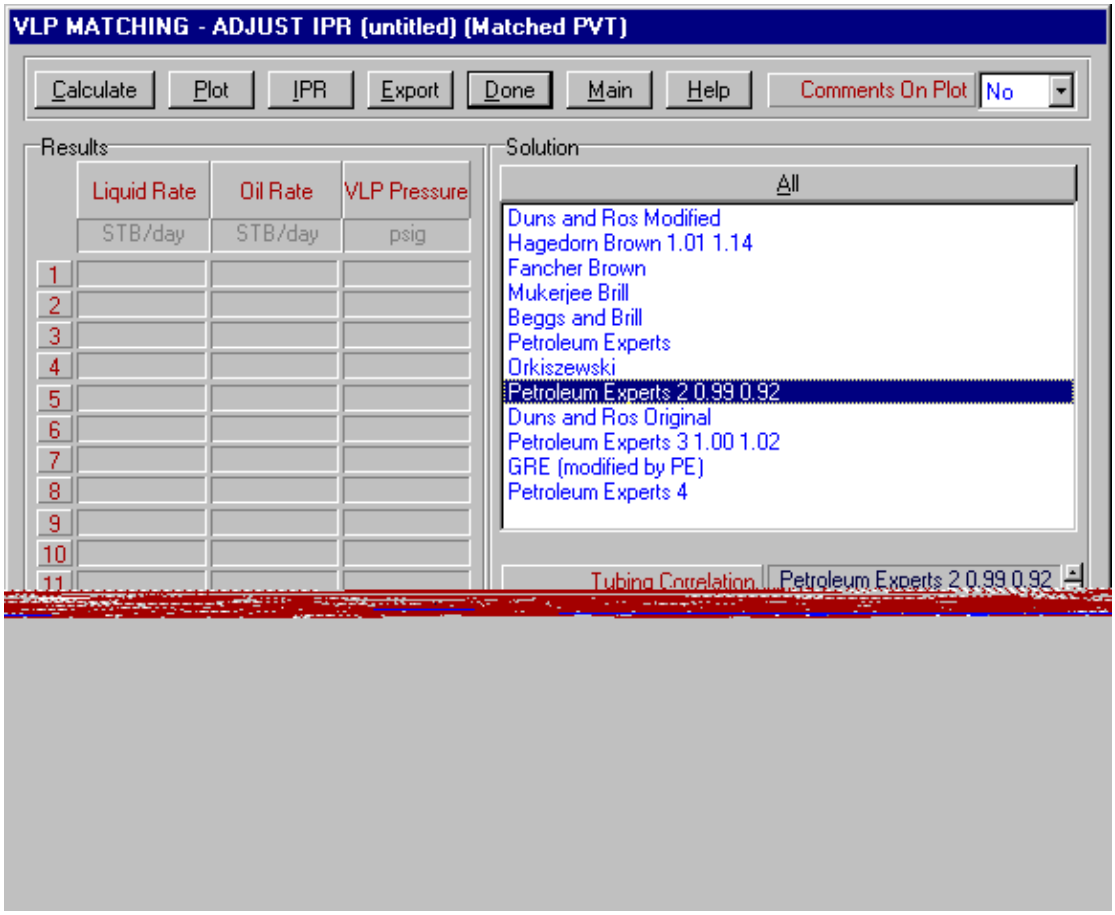


Figure 88: Calculate the BHFP

The purpose of this screen is to calculate the bottomhole flowing pressure for the test conditions. First we make sure that the right tubing correlation is selected. In our case, we are going to use *Petroleum Experts* 2. Then hit on **Calculate** to start the calculation. The results of the calculation will be shown and the calculated bottomhole flowing pressure will be shown.

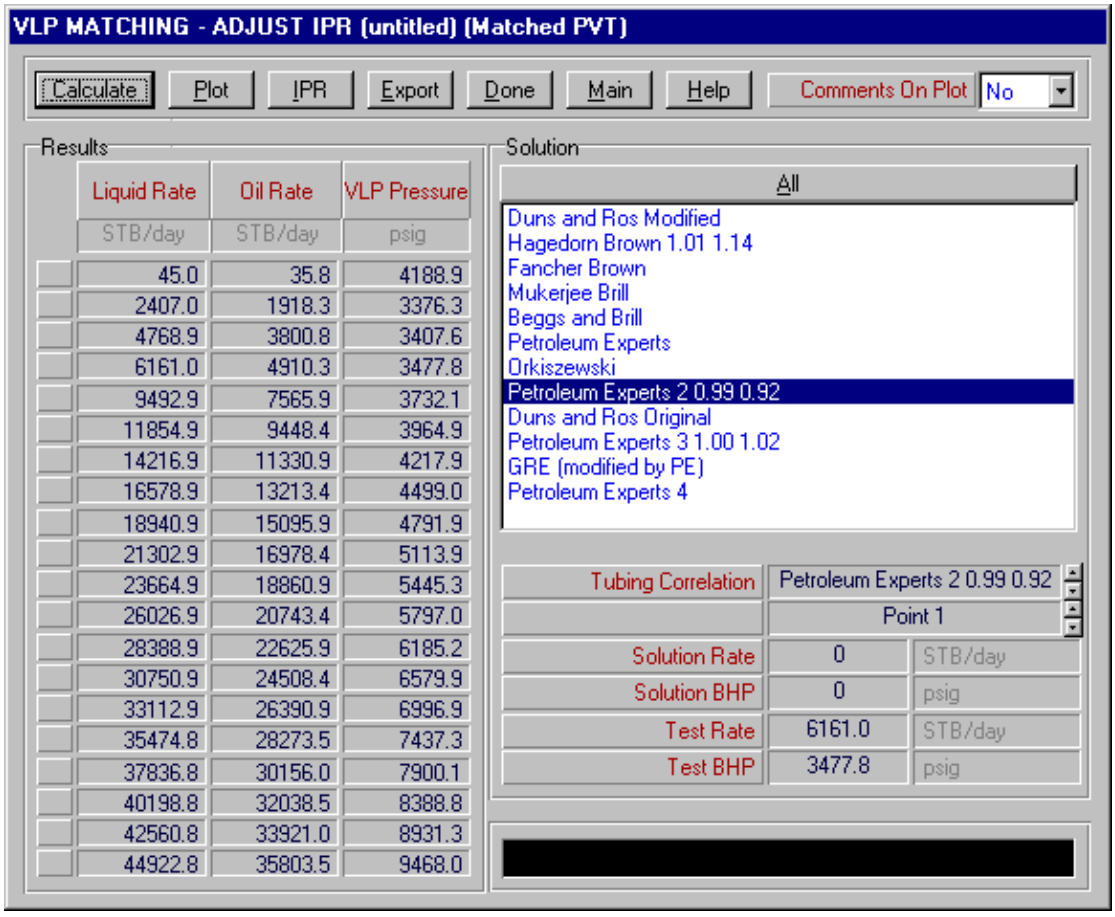


Figure 89: Calculated BHFP for the test rate

We can now hit on **IPR** to go to the IPR section.

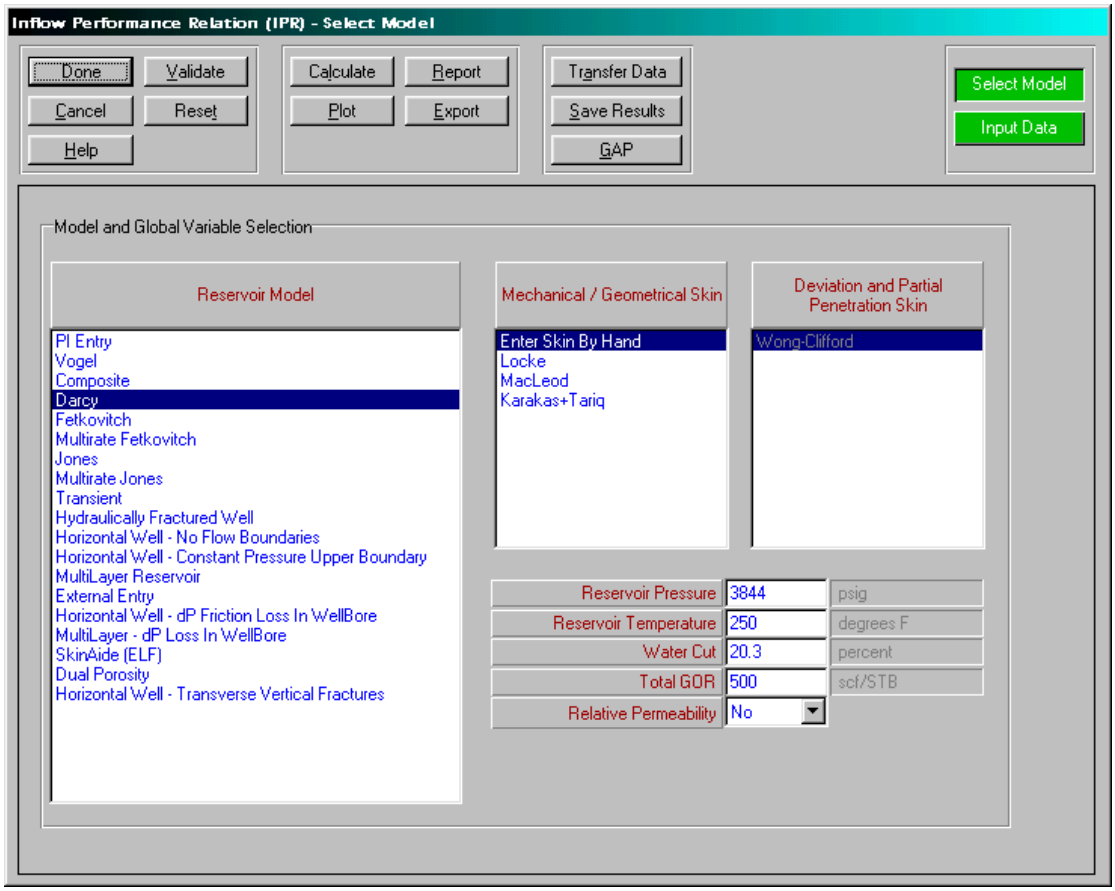


Figure 90: IPR section

Hit on Calculate to plot both the tuned VLP and IPR on the same plot and compare them to the test data.

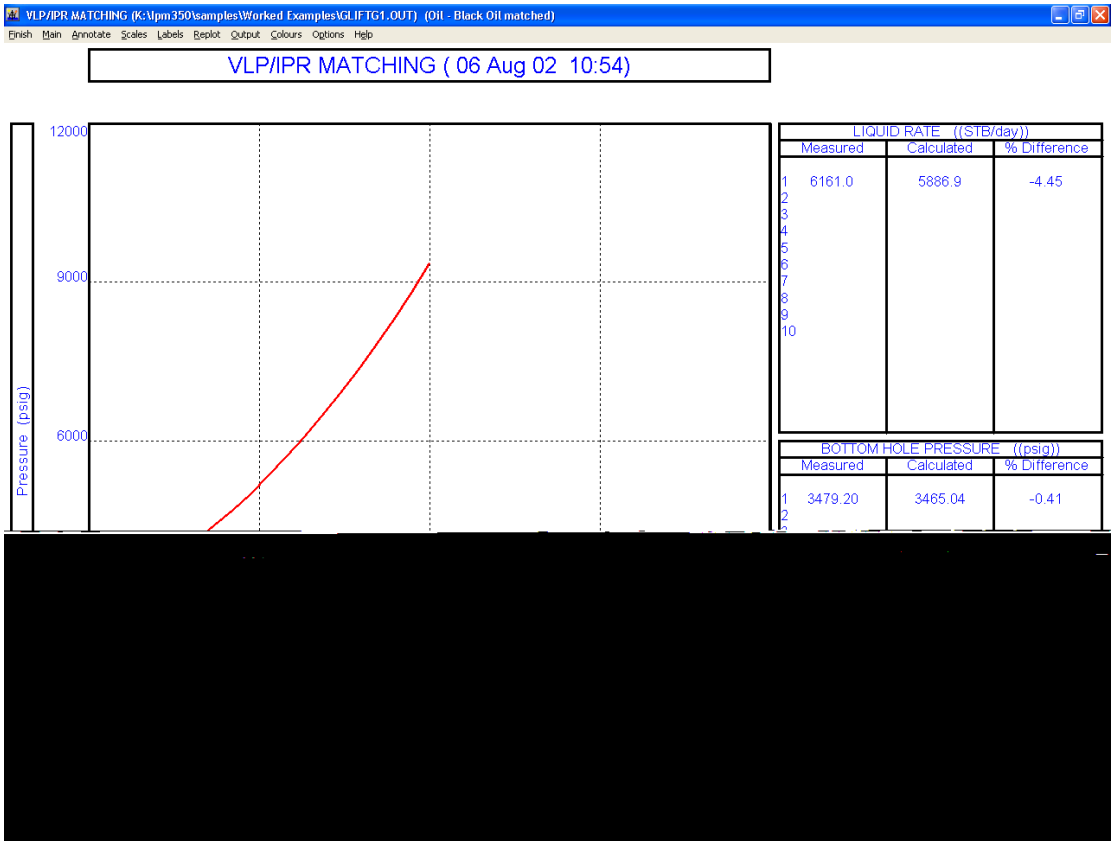

VLP/IPR MATCHING (K:\lpm350\samples\Worked Examples\GLIFTG1.OUT) (Oil - Black Oil matched)
Finish Main Annotate Scales Labels Replot Output Colours Options Help
VLP/IPR MATCHING (06 Aug 02 10:54)
12000
9000
6000
Pressure (psig)
LIQUID RATE ((STB/day))
Measured Calculated % Difference
1 6161.0 5886.9 -4.45
BOTTOM HOLE PRESSURE ((psig))
Measured Calculated % Difference
1 3479.20 3465.04 -0.41

Figure 91: Comparison of the current IPR model with the test data

The square box is the test point. The VLP and IPR should be intersecting at that point. The errors are displayed on the right of the screen. We can now adjust the IPR model to reduce the errors.

There is no fixed method to adjust the IPR. It depends on the conditions. For instance, if we are uncertain about the reservoir pressure, we can adjust the reservoir pressure. If we think that the value of skin has changed, we can adjust the skin value. In this exercise, we are going to change the reservoir pressure.

Click on Finish to close the plot window. Change the reservoir pressure in the IPR main screen to 3876 psig and hit on | Calculate again. We will see that the error has been reduced to a very small value and we have matched the IPR.

This finishes our matching of test data and data quality section. Go back to the main screen, and save the file as **GliftG1.out**.

3.1.3 Designing a New Gas Lift Well

Note: we will design for water cut of 50%. The gas available is 6 MMscf/day @ 1900 psig injection pressure at the top node.

Select the **Design | Gas Lift | New Well** menu item. Supply the following input data. We are asking for the gas lift valves to be casing sensitive. We also have selected the valves to be designed in such a way that they open at casing pressure:

Design rate method	Calculate from max production
Maximum liquid rate	20000 stb/day
Maximum gas available	6 MMscf/day
Maximum gas during unloading	6 MMscf/day
Flowing top node pressure	250 psig
Unloading top node pressure	250 psig
Operating injection pressure	1900 psig
Kick off injection pressure	1900 psig
Desired dP across valve	200 psi
Maximum depth of injection	13500 ft
Water cut	50%
Minimum spacing	500 ft
Static gradient of load fluid	0.45 psi/ft
Minimum transfer dP	25%
Maximum port size	32/64 ths inch
Safety for closure of last unloading valve	0 psi
Valve type	Casing sensitive
Min CHP decrease per valve	20 psi
Valve settings	All valves Pvo = gas pressure
Dome pressure correlation above 1200 psig	Yes
Check rate conformance with IPR	Yes
Vertical lift correlation	*Petroleum Experts* 2
Surface pipe correlation	Dukler Flannigan
Use IPR for unloading	No
Orifice sizing on	Calculated dP at orifice

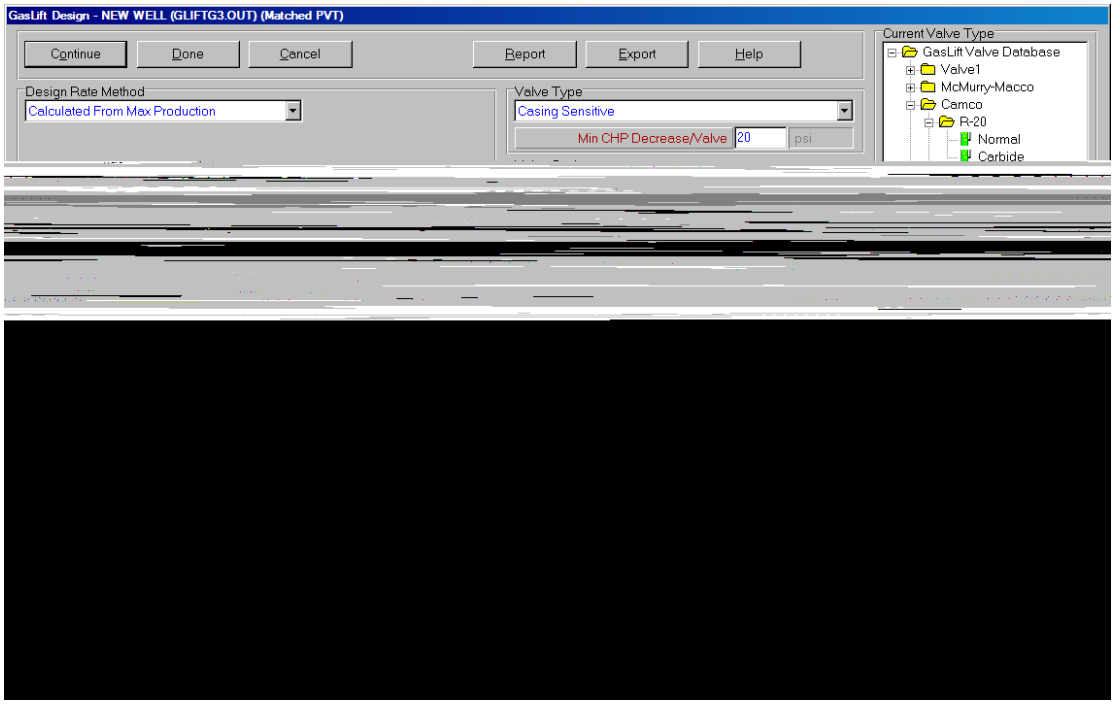


Figure 92: Gas lift design

Once the valve type has been selected, press **Done**. Then generate the gas lift performance curve by clicking the **Get Rate** button and then the **Plot** button at the top of the screen. This generated performance curve is as shown:

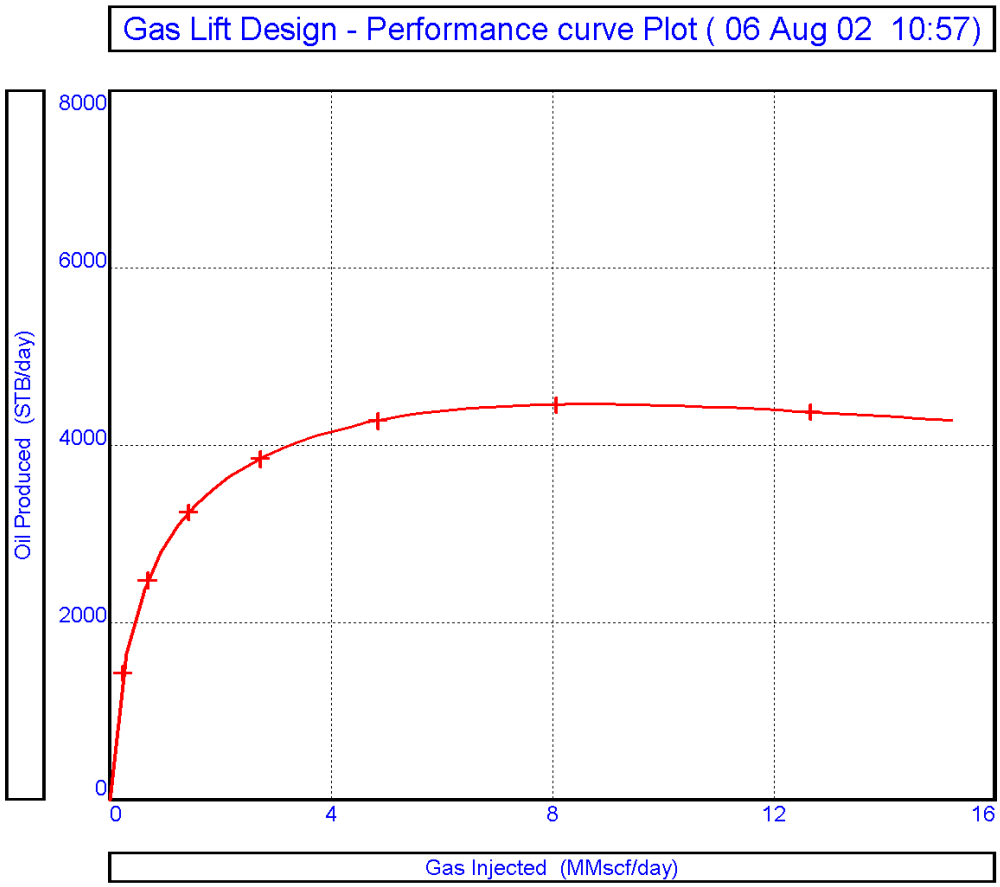


Figure 93: Gas lift performance curve

The performance curve of a gas lift design plots the oil rate produced with increased gas injection rates. To understand the shape of this curve, we will appeal to the notion that we do gas lift to decrease the pressure loss in the tubing string by decreasing the gravity component of pressure drop. The greater is the amount of gas injected, the lighter will be the fluid column.

However as the amount of gas injected increases, we also will be increasing the other component of pressure drop, i.e. the friction. A stage reaches in injection when any further increase in gas injection will increase friction component more than it will decrease gravity component. After this stage any increase in gas injection will decrease production rates. Thus the PC curve will go up and then come down as shown above and will have a maximum oil production rate and the gas injection required corresponding to this rate will be optimum. If we look at the performance curve we see that at a gas lift rate of 6 MMscf/day the oil production is around 4440 stb/day. The maximum oil production of 4600 stb/day occurs for gas lift rate of approximately 9.3 MMscf/day. From this plot **PROSPER** determines the gas lift required for maximum oil production. This is the optimum gas lift rate for this well. In case the available gas is higher than the optimum gas required, the program will only inject the optimum gas into the well, which is 9.3 MMscf/day in this case. In case the available gas is less than optimum gas, the actual available gas value will be used. If we proceed with design at this stage by pressing the **Design** on the following screen, **PROSPER** will design this case using 6.0 MMscf/day of gas.

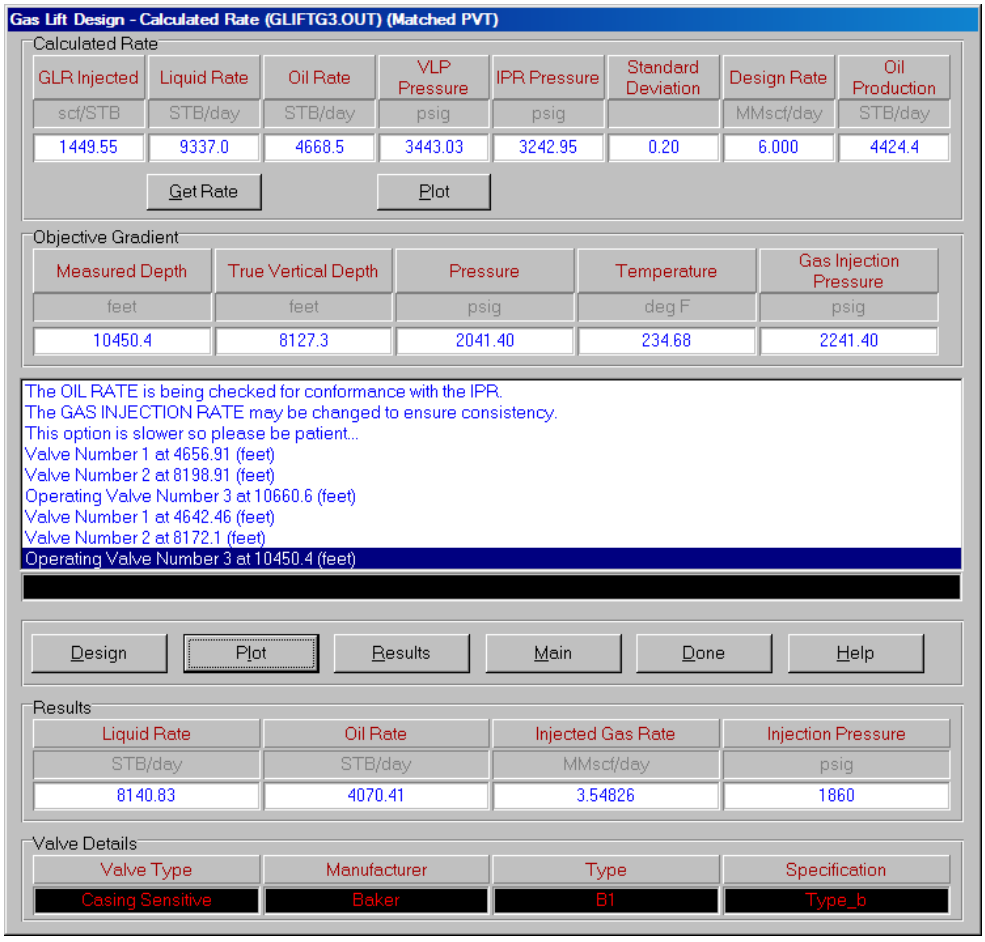


Figure 94: Gas lift design

To see a plot of the Gas lift design click the **Plot** button at the bottom of the above screen and the following plot will appear.

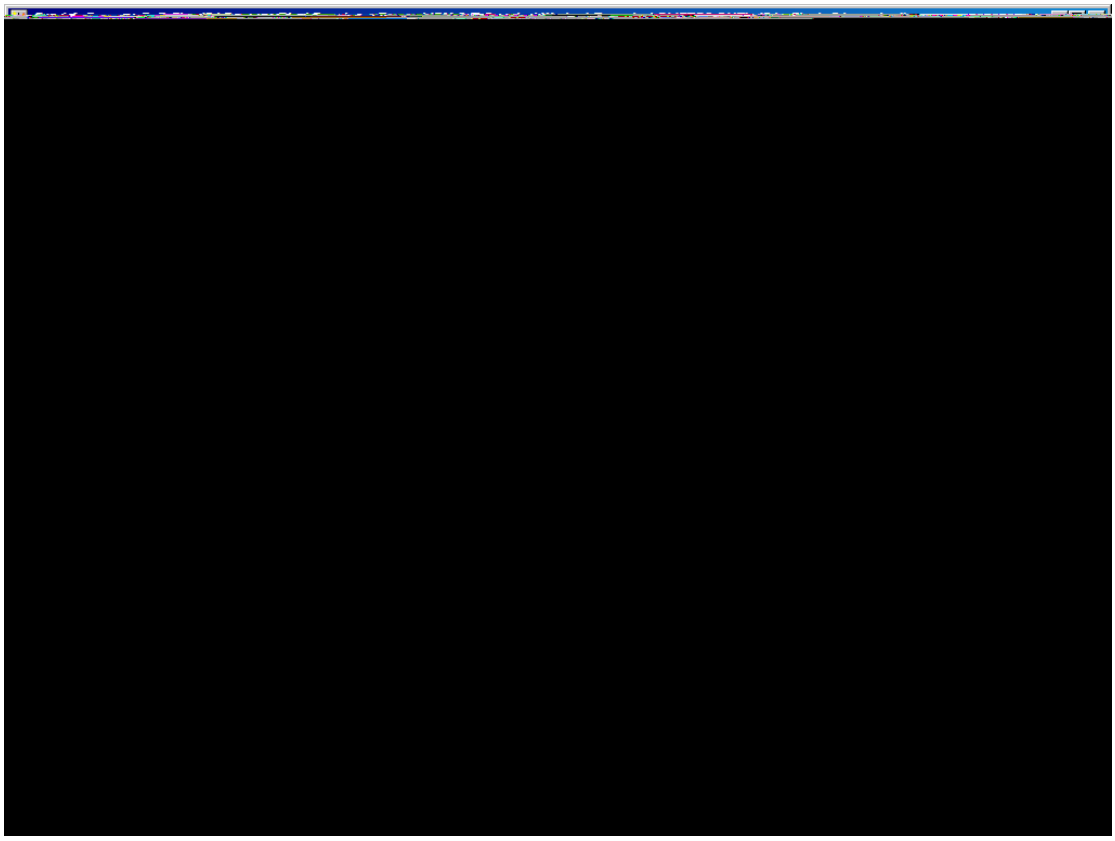


Figure 95: Gas lift design plot

If we press **Finish** we will exit the plot and return to design screen. On this screen if we press the **Results** button, the following screen with the results of gas lift design will appear. On the screen given below if you press **Calculate**, ***PROSPER*** will calculate the dome pressure settings for you.

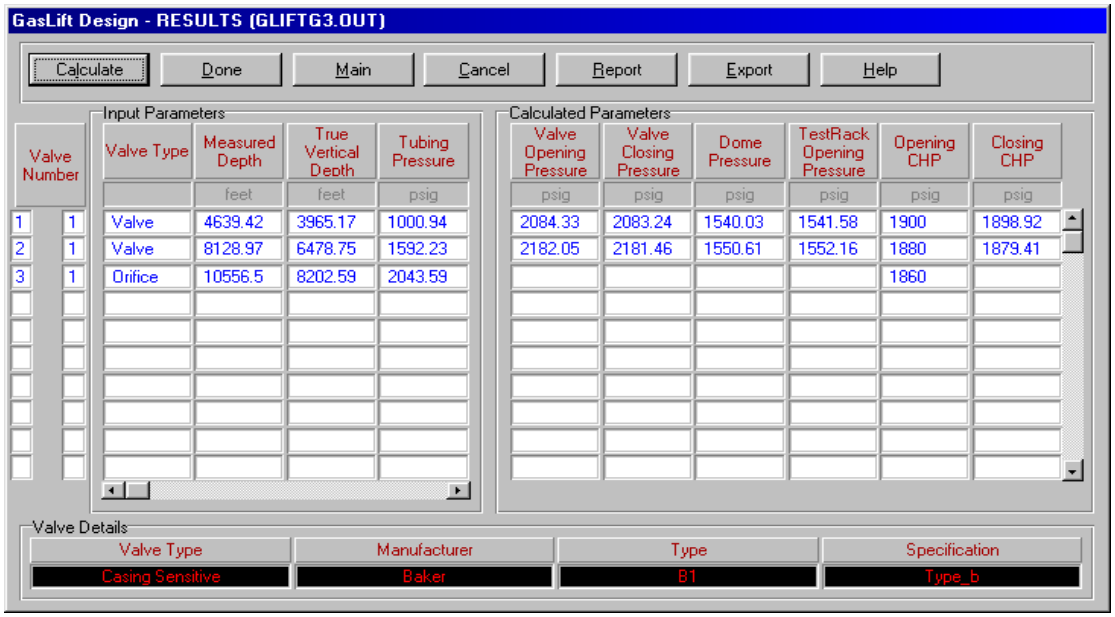


Figure 96: Gas lift design results

This finishes the gas lift design. Go back to the main screen, and save the file as **GliftG2.out**.

3.1.4 Using QuickLook as a Diagnostic Option to Check the Gas Lift Design

➔ **Note:** In this section we are going to use the QuickLook option as a diagnostic tool and see if the existing gas lift set up is performing as per design. We will use the design of the previous section, selected on the basis of a 50% future water cut and try to do the study for 20.3 % current water cut.

We will start from the **Matching – QuickLook** menu option. To start with let us say we have current flowing conditions as per data set one defined at the start of the tutorial.

To start with let us say we have the following oil rate, water cut, pressure, lift gas rate and temperature data for the well:

Tubing head pressure	264 psig
Tubing head temperature	160.7 degree F
Liquid rate	6161 stb/day
Water cut	20.3 %
Total gas rate	6.555 MMscf/day
Gas injection rate	4.1 MMscf/day
Casing head pressure	1750 psig

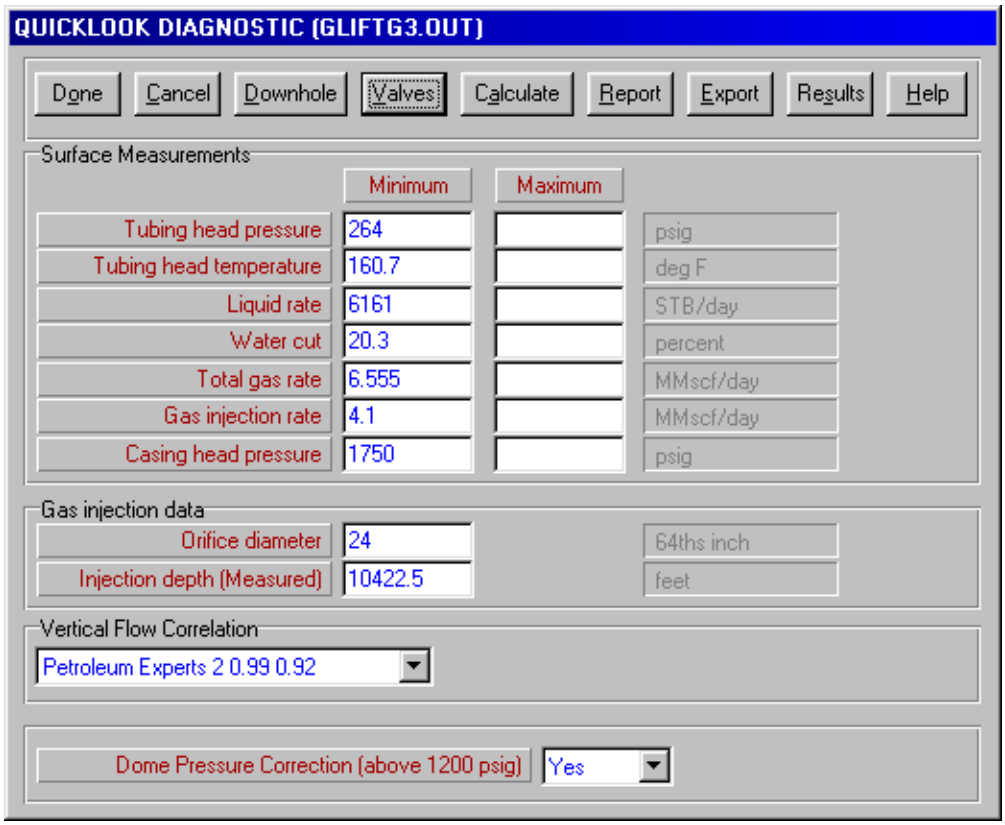


Figure 97: QuickLook entry screen

To enter the valve data, press the **Valves** button on the above screen. The following screen appears:

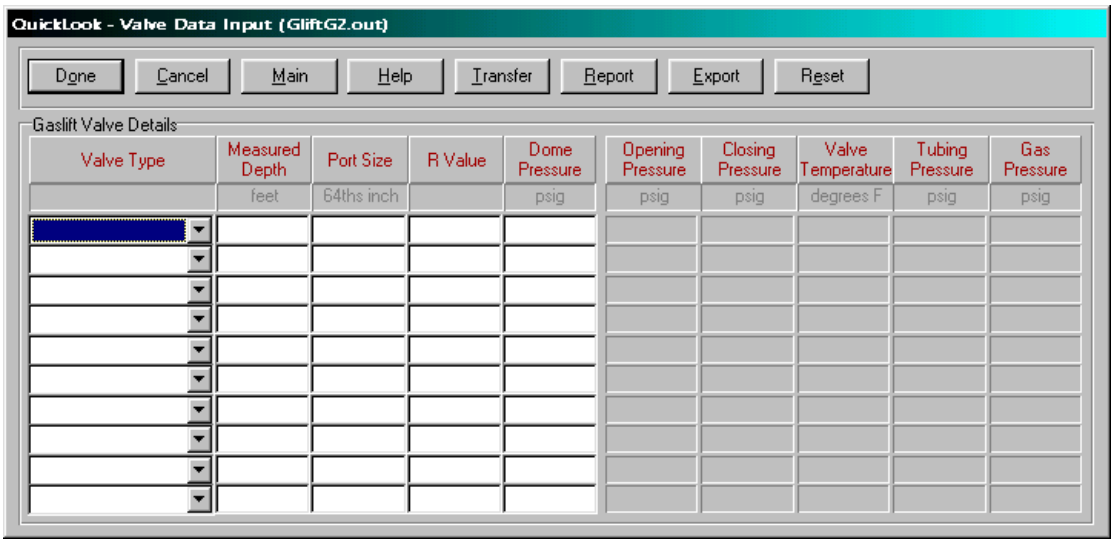


Figure 98: Valve depth specification

We can transfer the valve data from the design we have just done by pressing **Transfer** on the above screen and pressing **Gas Lift Design** on the screen below. Note that this is the gas lift design got for the case when we fixed oil production to 4000 stb/day in the previous section.

Figure 99: Transfer valve data

Next click on **Done | Calculate | Calculate | OK | Plot** to get the following diagnostic plot:

QUICKLOOK DIAGNOSTIC (C:\Peppe\Program testing\Worked Examples\GLIFTG3.OUT) (Oil - Black Oil matched)
Finish Main Annotate Scales Labels Replot Output Colours Options Test Data Help
QuickLook (19 Aug 03 15:00)
X:

Figure 100: QuickLook calculation plot

To analyze this plot, let us examine the QuickLook principle. In this method we calculate well pressure traverses for both tubing and casing pressure in two directions: one beginning from the wellhead and going to the sand face, and the other going from the sand-face up to the wellhead.
To change the assumptions, we must understand the factors that affect these traverses.
The downward gradients are based on measured data (THP, CHP, gas and liquid flow rates, WC, GOR), while the upward gradients depend on the inflow (in the case of the tubing pressure) and on the pressure drop across the orifice (as regards the casing pressure).
If our assumptions about the gas lift rates, oil flows etc., are correct, the two pressure traverses should be identical. If not we have to change these assumptions until we get identical traverses.
In **Figure 100** we see that the tubing traverse calculated starting from the flowing bottomhole pressure is higher than the measured tubing traverse. This suggests that the inflow potential is too high, so the reservoir pressure should be lower than considered. Let's decrease the reservoir pressure down to 3050 psi.
The QuickLook calculated is now:

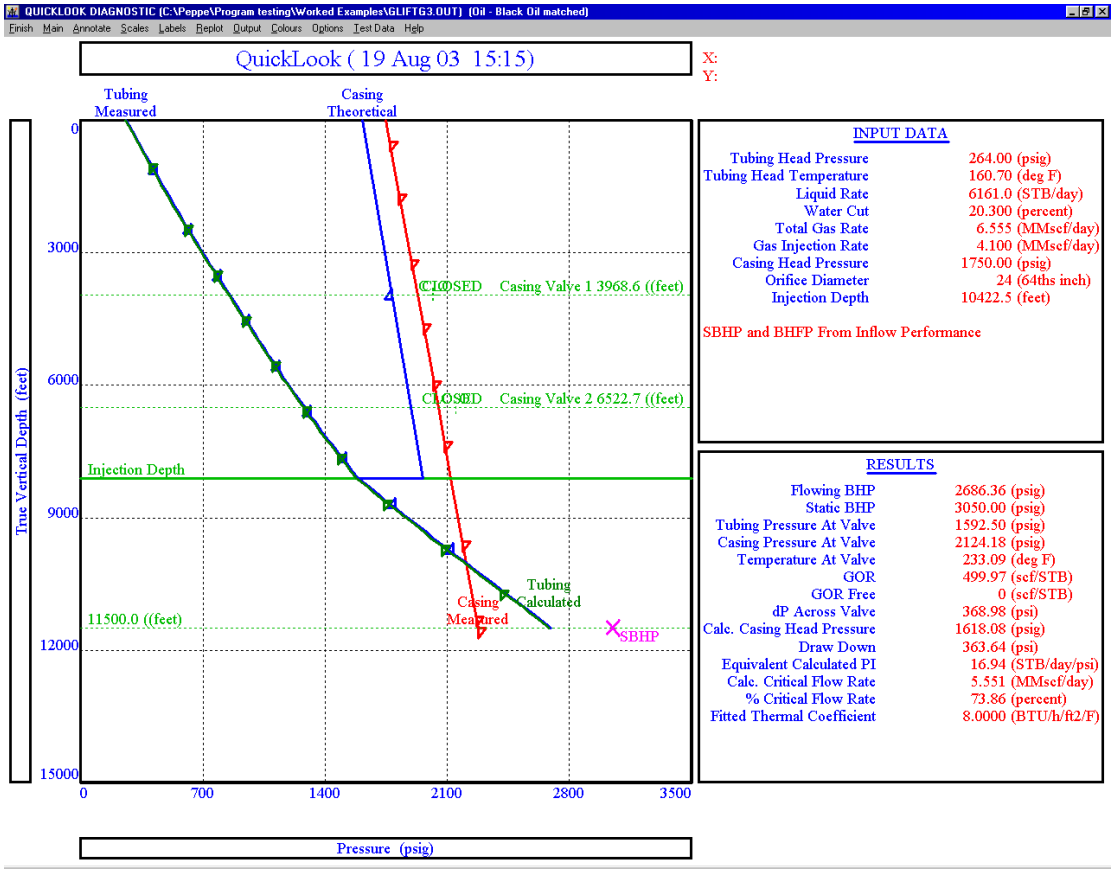


Figure 101: QuickLook calculation plot 2

The tubing curves now overlap.

Next let us see how pressure traverse curves compare in the casing above the orifice.
The calculated upward casing traverse is now smaller than the measured one. This suggests that the pressure drop across the orifice for some reason (like scaling) has increased. So, in order to match the two gradients, a smaller orifice diameter can be chosen. Let us decrease it to 22/64” and re-perform QuickLook calculations, the plot then looks like below:

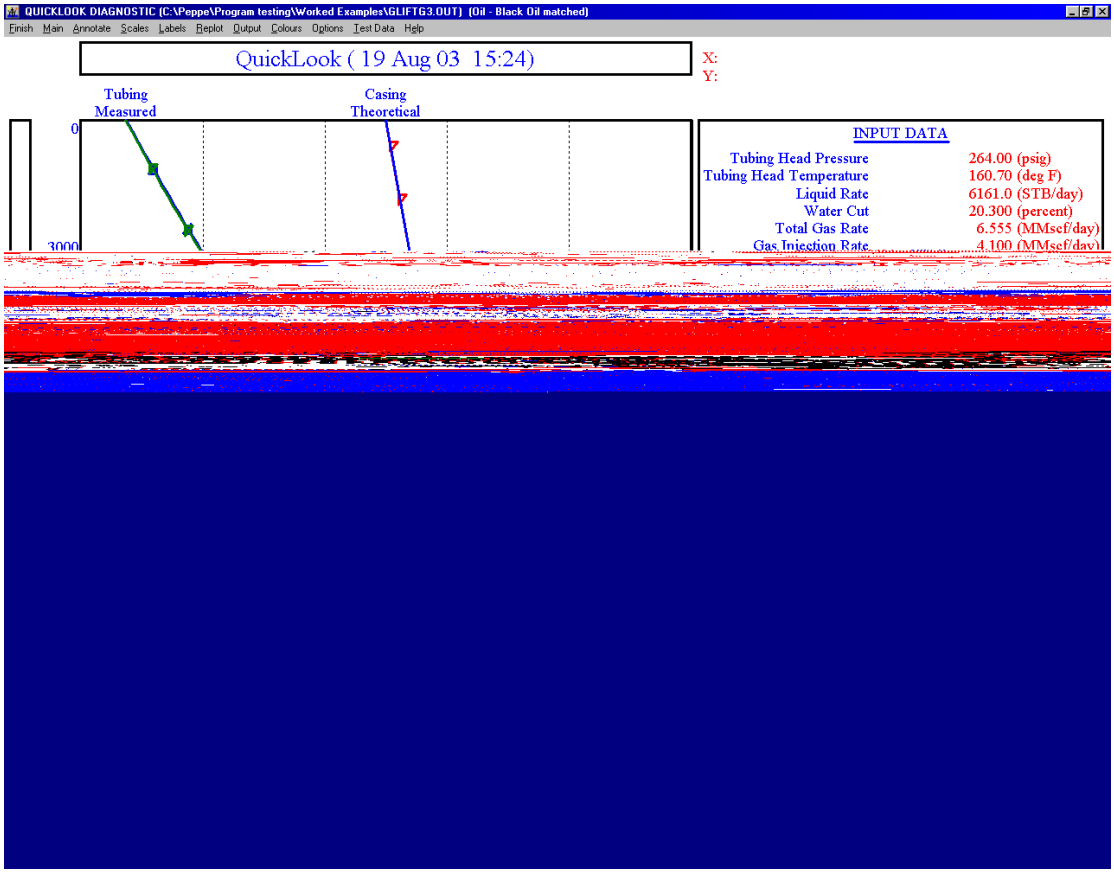

QUICKLOOK DIAGNOSTIC (C:\Peppe\Program testing\Worked Examples\GLIFTG3.OUT) (Oil - Black Oil matched)
Finish Main Annotate Scales Labels Replot Output Colours Options Test Data Help
QuickLook (19 Aug 03 15:24)
X:
Y:
Tubing Measured
Casing Theoretical
0
3000
INPUT DATA
Tubing Head Pressure 264.00 (psig)
Tubing Head Temperature 160.70 (deg F)
Liquid Rate 6161.0 (STB/day)
Water Cut 20.300 (percent)
Total Gas Rate 6.555 (MMscf/day)
Gas Injection Rate 4.100 (MMscf/day)

Figure 102: QuickLook calculation plot 3

These results are good and based on this we can predict the oil flow rates and gas injection rates fairly. This method also can be used to trouble shoot and check the performance of operating wells, if we have down-hole and reliable flow measurements available.

Save the file as GliftG3.out.

3.2 PROSPER ESP Example

3.2.1 Setting up the Basic Model

Run **PROSPER** and go to the **Option** menu in **PROSPER** and select the following options:

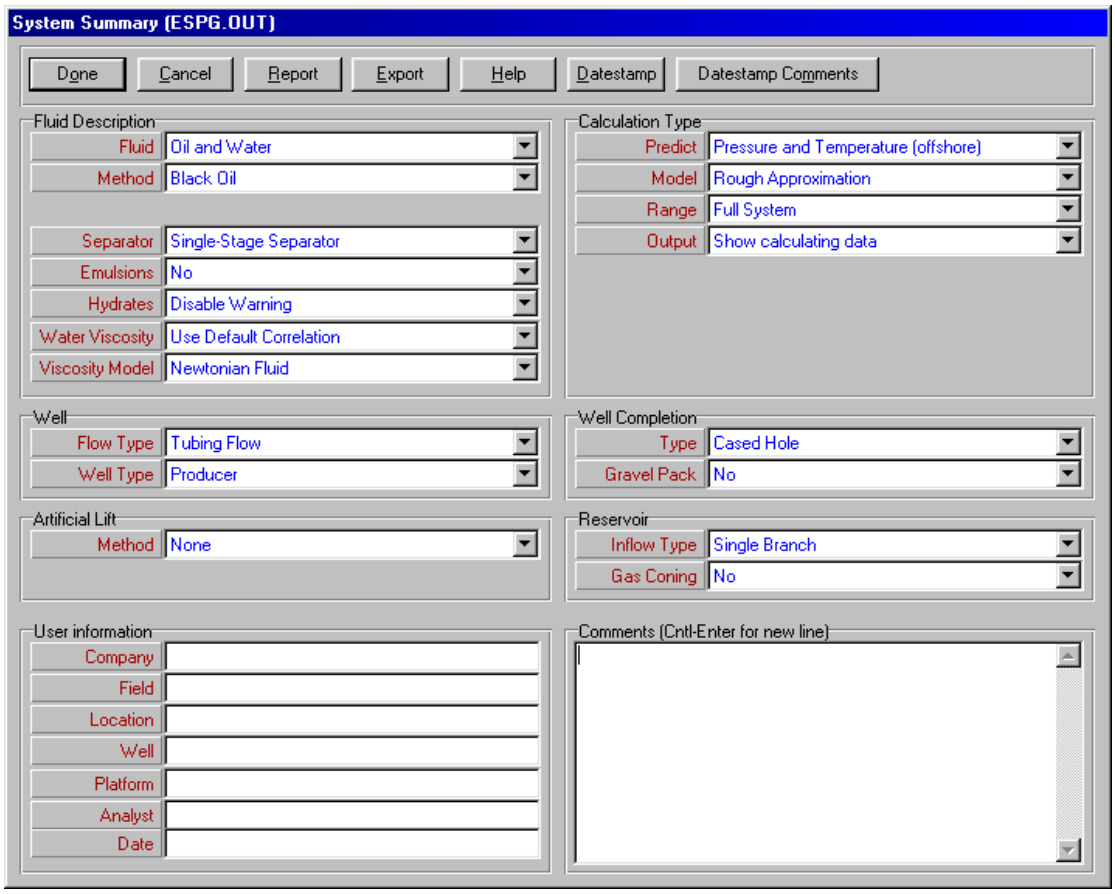


Figure 103: Setting the model option

In this screen we have specified:

- The handled fluid is an oil
- **PVT** behavior will be modeled as a Black oil, with a single stage separation scheme.
- This is an offshore well
- We want to do temperature predictions using rough approximation method.
- The fluid flows through the tubing
- No emulsion forms
- For the moment we have no ESP in the system; the reason will be given further on.
- It is a cased hole with no gravel pack.
- We also do not have gas coning and the inflow is simple and not multilateral.

Next in the main screen go to the **PVT | Input Data** and fill in the **PVT** data as indicated in the available data section.

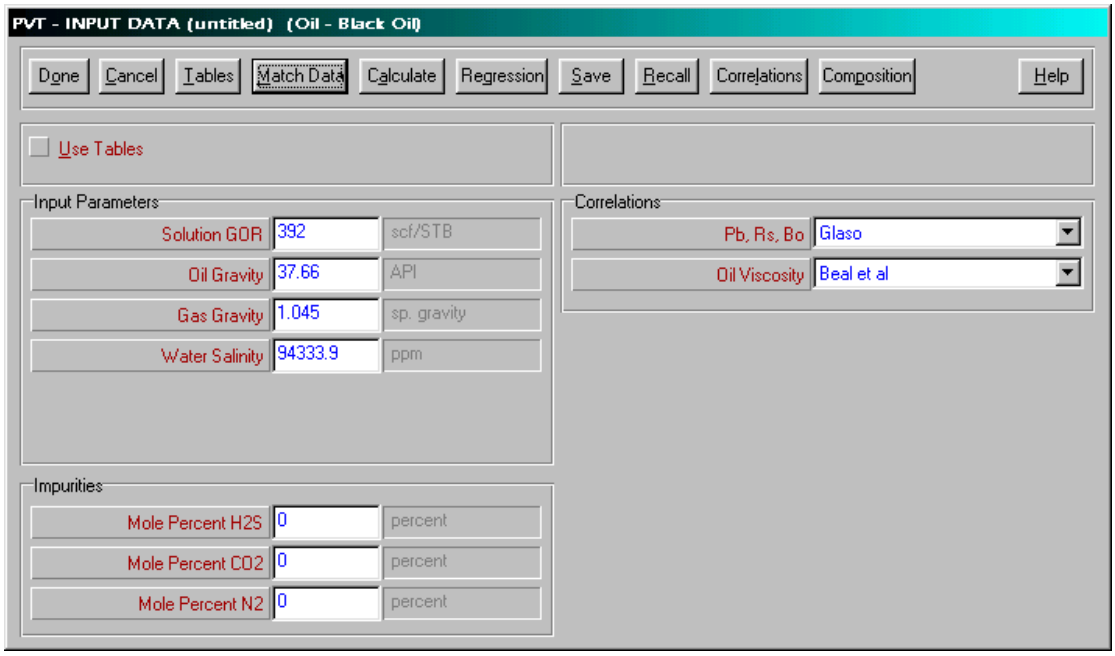


Figure 104: **PVT** input data

Since we do have lab data, we should match them to the existing Black oil Correlation. Enter the **PVT** match data that we have by clicking the Match Data button on the above screen. Enter the match data as follows:

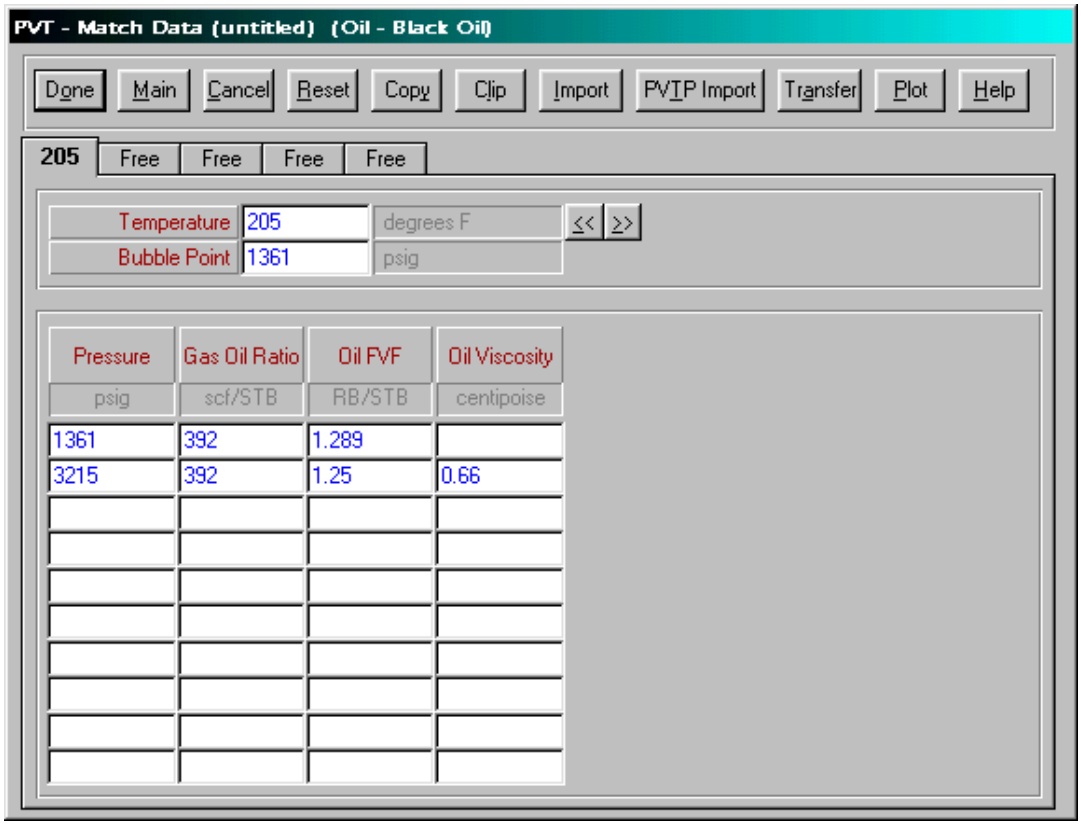


Figure 105: **PVT** match data

Once you have entered measured data, go back to the previous dialog by clicking the **Done** button and perform the matching calculation by clicking on the **Regression** button and then the **Match All** button. The program does a regression analysis on all

the entered data with all standard black oil correlations that are available in **PROSPER**.

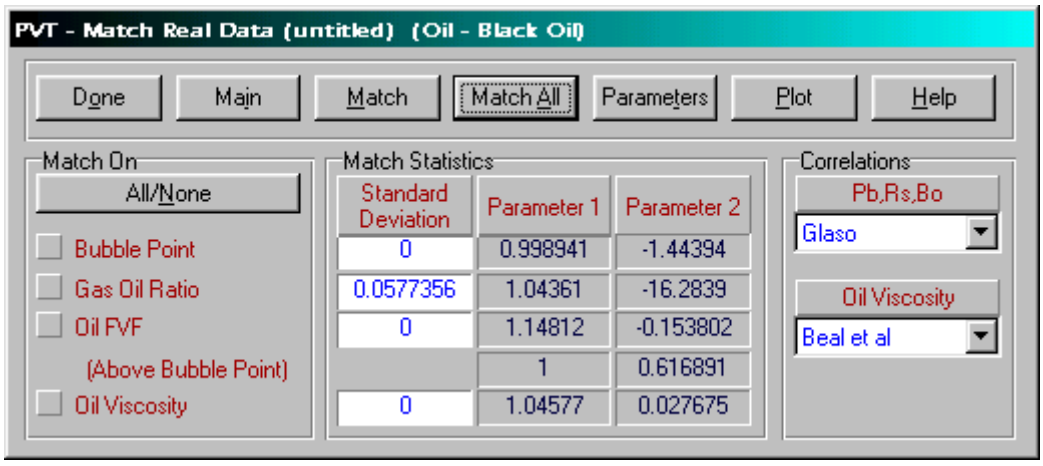


Figure 106: **PVT** matching

To display the regression parameters and standard deviations for all the correlations, click on Parameters.

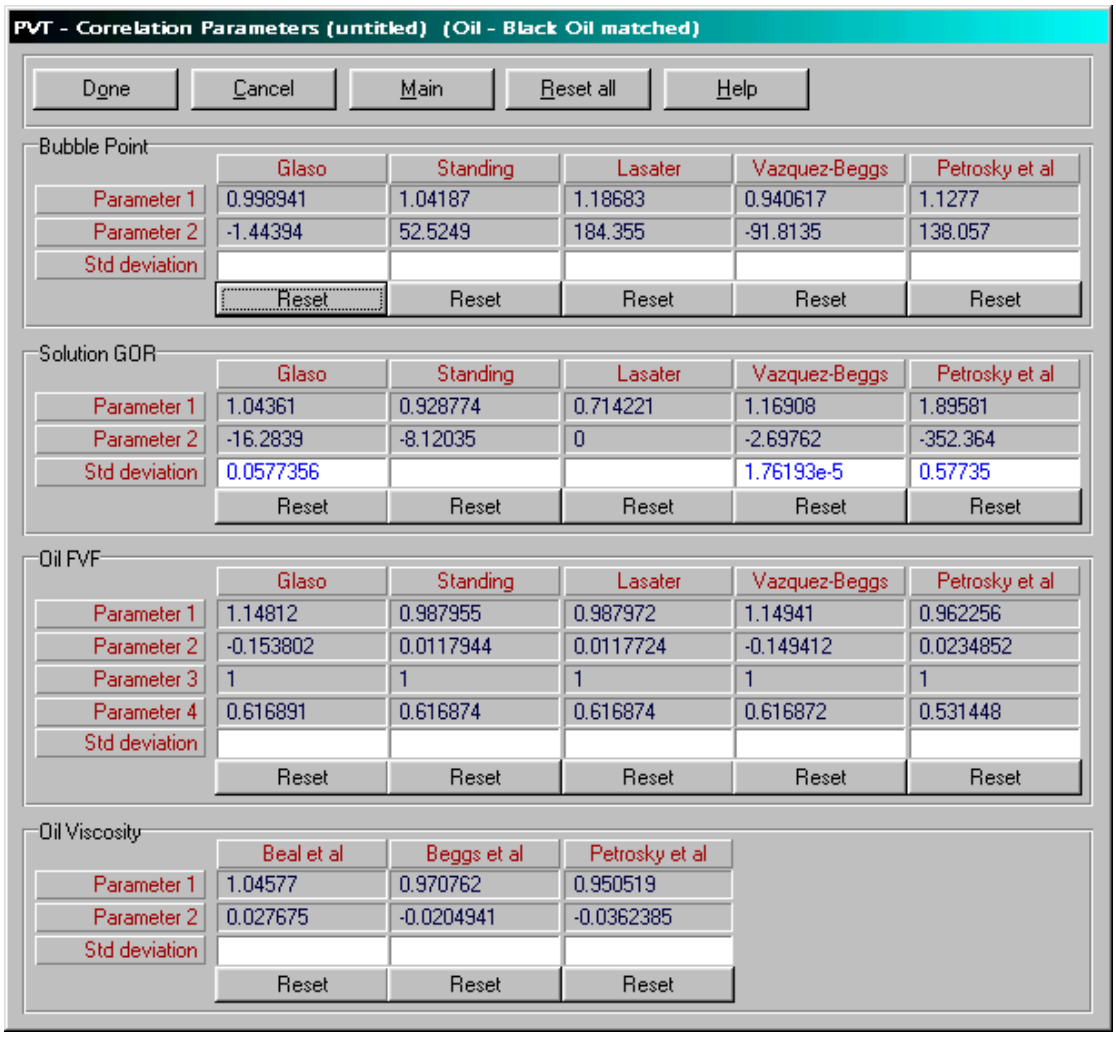

PVT - Correlation Parameters (untitled) (Oil - Black Oil matched)
Done
Cancel
Main
Reset all
Help
Bubble Point
Glaso Standing Lasater Vazquez-Beggs Petrosky et al
Parameter 1 0.998941 1.04187 1.18683 0.940617 1.1277
Parameter 2 -1.44394 52.5249 184.355 -91.8135 138.057
Std deviation
Reset Reset Reset Reset Reset
Solution GOR
Glaso Standing Lasater Vazquez-Beggs Petrosky et al
Parameter 1 1.04361 0.928774 0.714221 1.16908 1.89581
Parameter 2 -16.2839 -8.12035 0 -2.69762 -352.364
Std deviation 0.0577356 1.76193e-5 0.57735
Reset Reset Reset Reset Reset
Oil FVF
Glaso Standing Lasater Vazquez-Beggs Petrosky et al
Parameter 1 1.14812 0.987955 0.987972 1.14941 0.962256
Parameter 2 -0.153802 0.0117944 0.0117724 -0.149412 0.0234852
Parameter 3 1 1 1 1 1
Parameter 4 0.616891 0.616874 0.616874 0.616872 0.531448
Std deviation
Reset Reset Reset Reset Reset
Oil Viscosity
Beal et al Beggs et al Petrosky et al
Parameter 1 1.04577 0.970762 0.950519
Parameter 2 0.027675 -0.0204941 -0.0362385
Std deviation
Reset Reset Reset

Figure 107: Match parameters

Based on the these regression parameters (parameter 1, which is multiplier and parameter 2 which is a shift factor) and standard deviation select the best model. Ideally the std deviation should be very small, parameter 1 should equal 1.0 and parameter 2 should equal zero. In this case we select Beggs et al correlation for viscosity modelling and Standing for all other proprties. Once this is done, click the Main button to go back to the main window. Please set the correlations in the main **PVT** screen (see below)

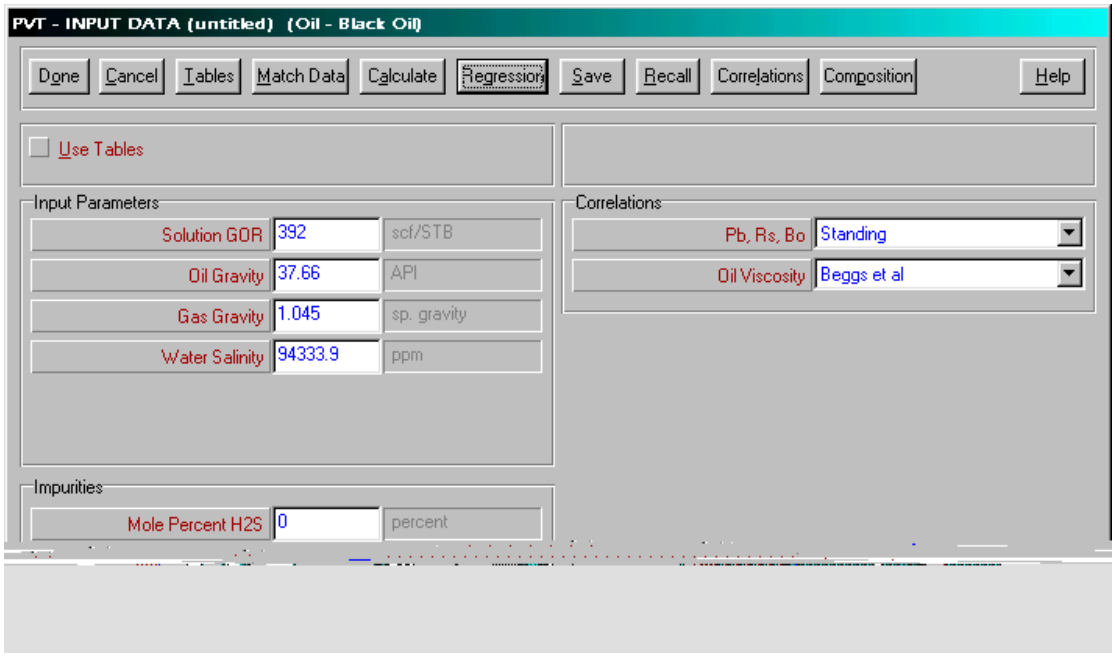


Figure 108: Choose the correlation

After finishing the **PVT** match i.e. providing the model with an adequate fluid description, we have to specify our well bore. To do so in the main screen, select the **System | Equipment (Tubing etc.)** menu item and input the equipment data as follows:

Deviation Survey:

It is given the deviation survey as follow:

Measured depth (ft)	True vertical depth (ft)
0	0
463.3	463.3
2399.9	2368.4
3450.1	3256.6
4649.9	4100.1
5200.1	4467.5
6899.9	5673.9
7450.1	6079.7
8687.7	7280.2

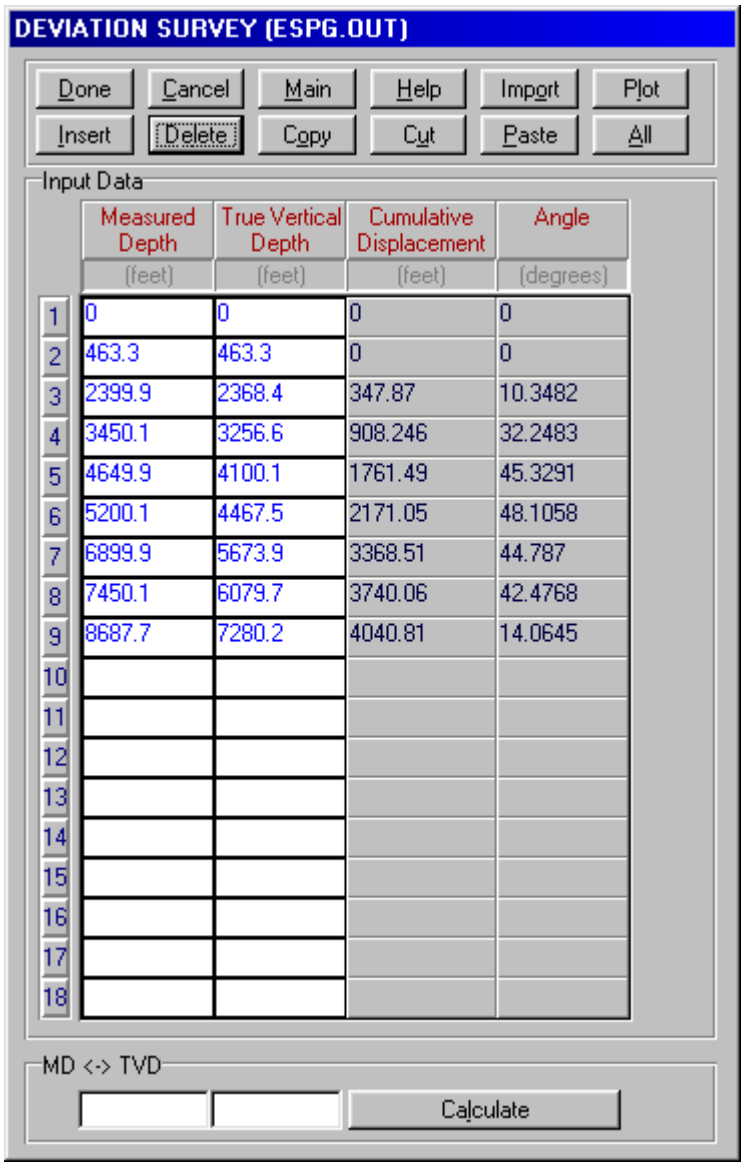


Figure 109: Deviation survey

This survey is taken as the basis for calculating true depths, in the model. It is recommended to use zero of this survey as the reference depth for all further entries. If we use the zero of deviation survey as the reference depth, then it is easier to enter

well bore data as all the depths indicated in the well bore data refer to deviation survey. Once we have supplied the deviation survey, the well bore details are entered as follows:

Down-hole equipment:
It is given the down hole equipment as follow:

Type	MD (ft)	Tubing ID (in)	Tubing OD (in)	Casing ID (in)
X'mas tree	59.4	-	-	-
Tubing	689.0	3.96	4.5	8.68
SSSV	-	2.13	-	-
Tubing	7660.8	3.96	4.5	8.68
Restriction	-	2.31	-	-
Tubing	7677.2	3.96	4.5	8.68
Casing	7860.9	-	-	8.68
Casing	8169.3	-	-	6.18
Casing	8687.7	-	-	3.96

All roughness of tubing / casing = 0.0006 in

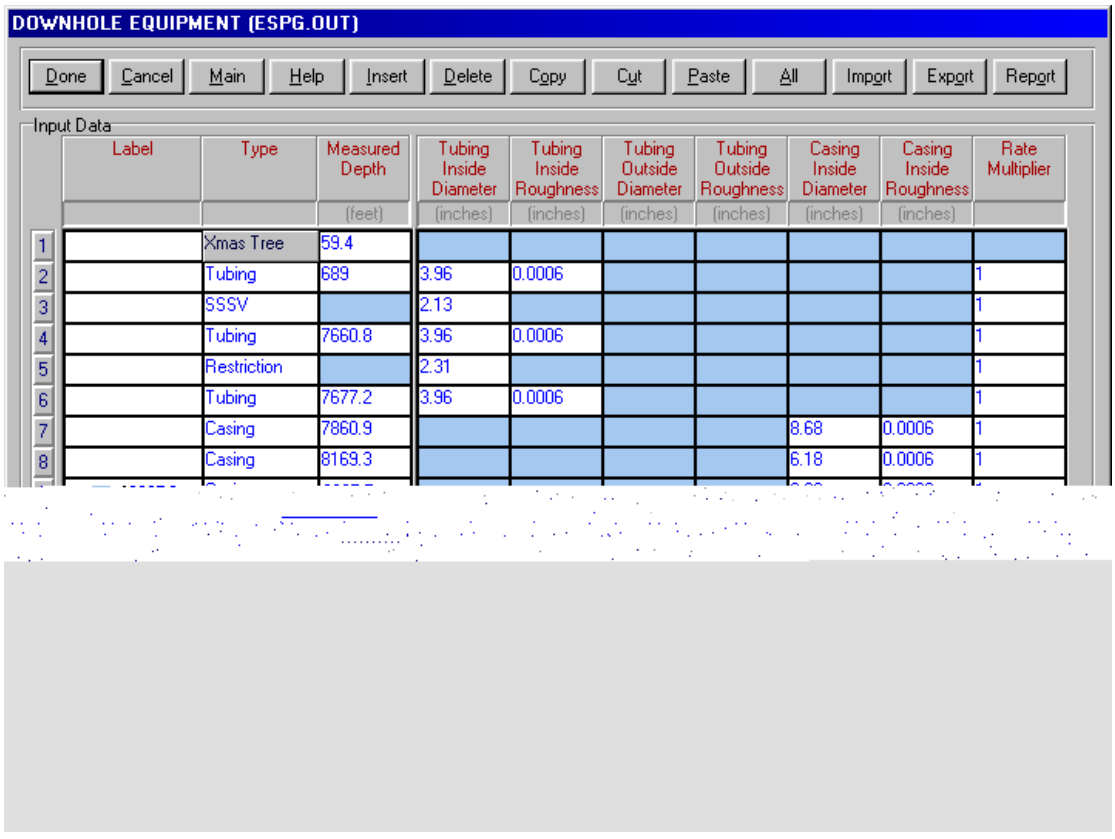


Figure 110: Downhole equipment

The data regarding tubing outside diameter will be used further on, when the ESP option will be selected.
Next we want to specify the geothermal gradient and the overall heat transfer coefficient, as we are doing temperature predictions as well.

Geothermal Gradient:

It is given the Geothermal gradient as follow:

Measured depth (ft)	Formation temperature (degree F)
59.4	60
8687.7	205

Overall heat transfer coefficient 3 BTU/hr/ft2/F

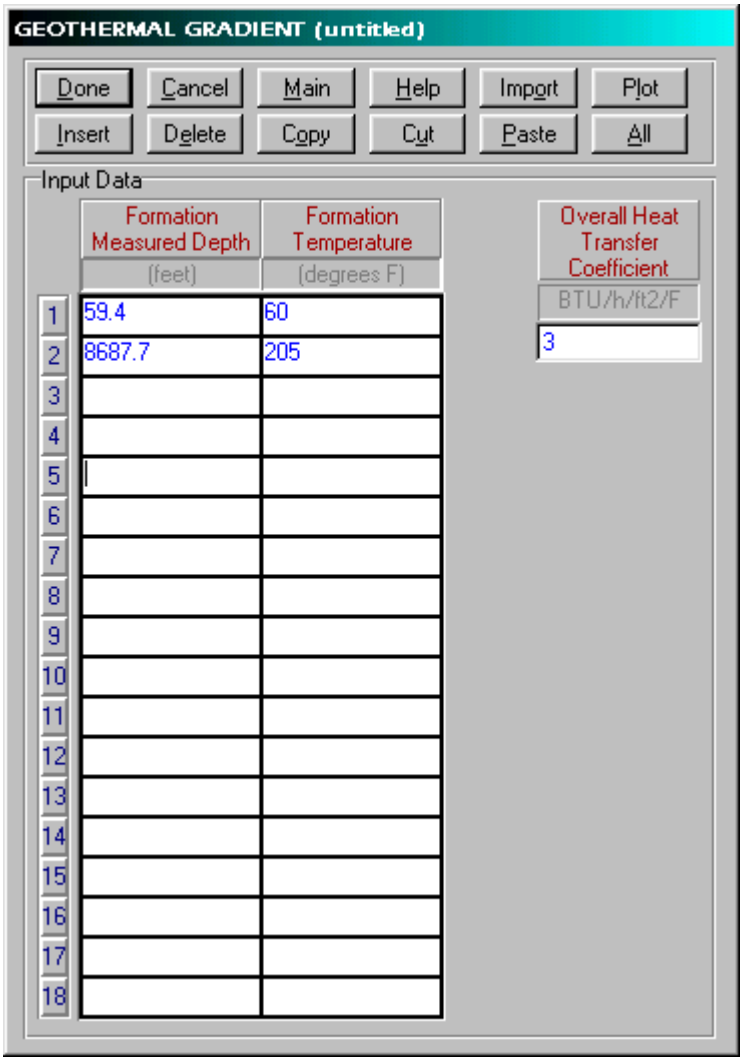


Figure 111: Geothermal gradient

Note: There is no surface equipment. Leave the heat capacities to default values.

After specifying the well bore we will want to build an inflow model into the well bore. So, next select the **System | Inflow Performance** menu item and select the IPR model and enter the IPR data as shown in the following dialogs:

Reservoir model	PI Entry
Reservoir pressure	2468 psig
Reservoir temperature	205 degree F
Water cut	6 %
Total GOR	392
Relative permeability	No

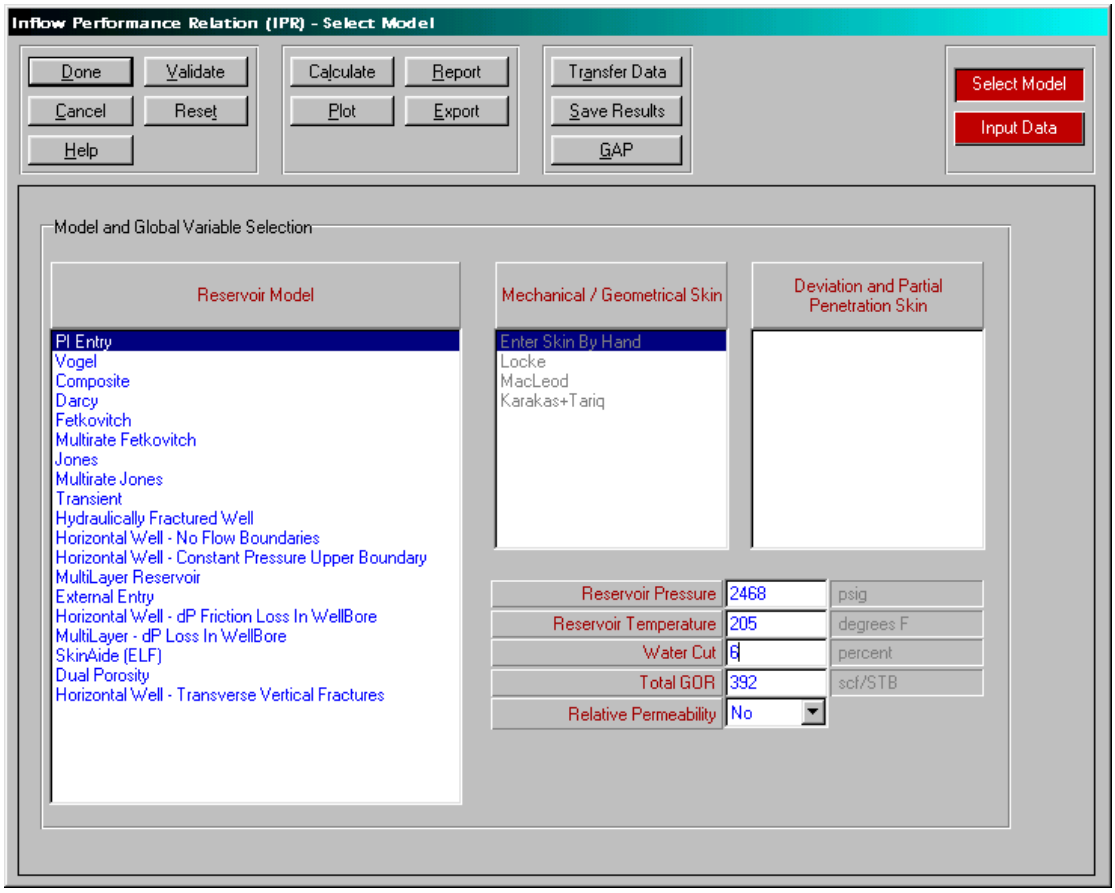


Figure 112: Selecting the IPR model

We have selected the simple PI model for the Inflow Performance. For this model to supply input data if we click on the **Input Data** button of this screen, we get the following screen and we can enter a PI of 7.19 STB/day/psi.

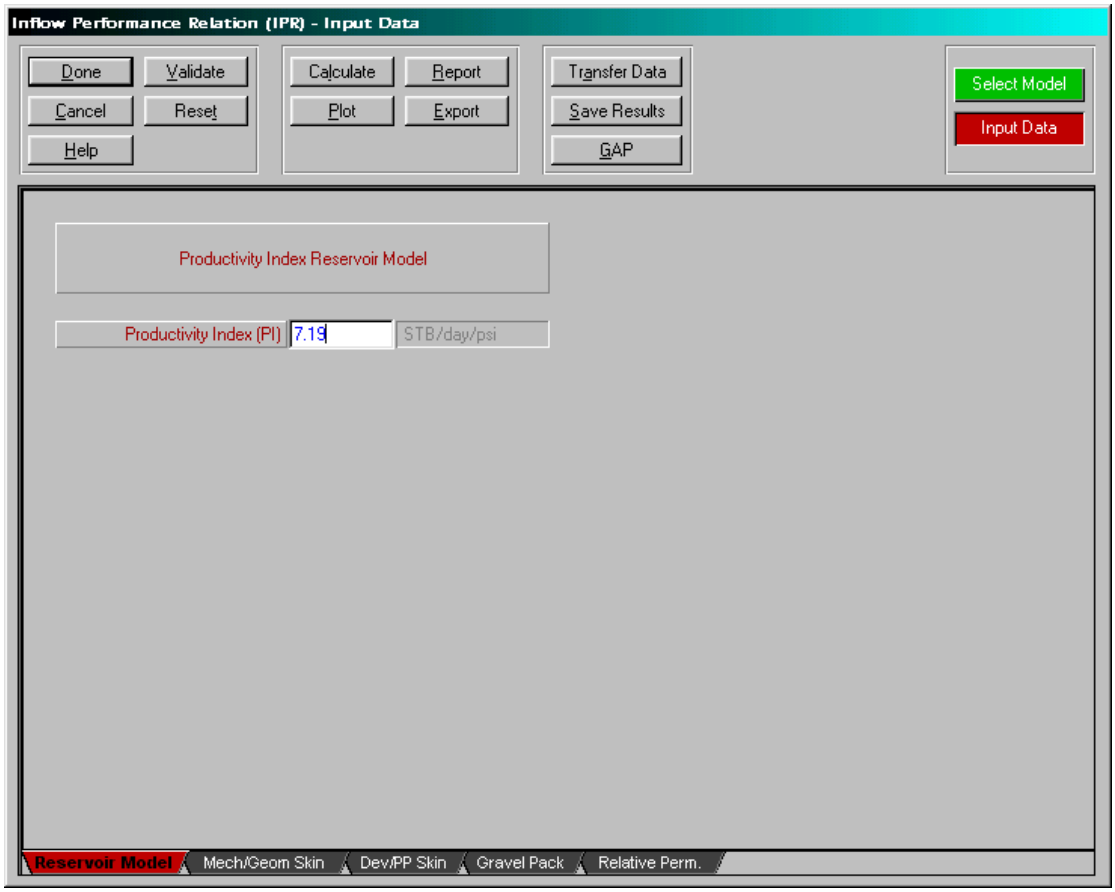


Figure 113: Entering PI value

Click the **Calculate** button – this should plot the following IPR:

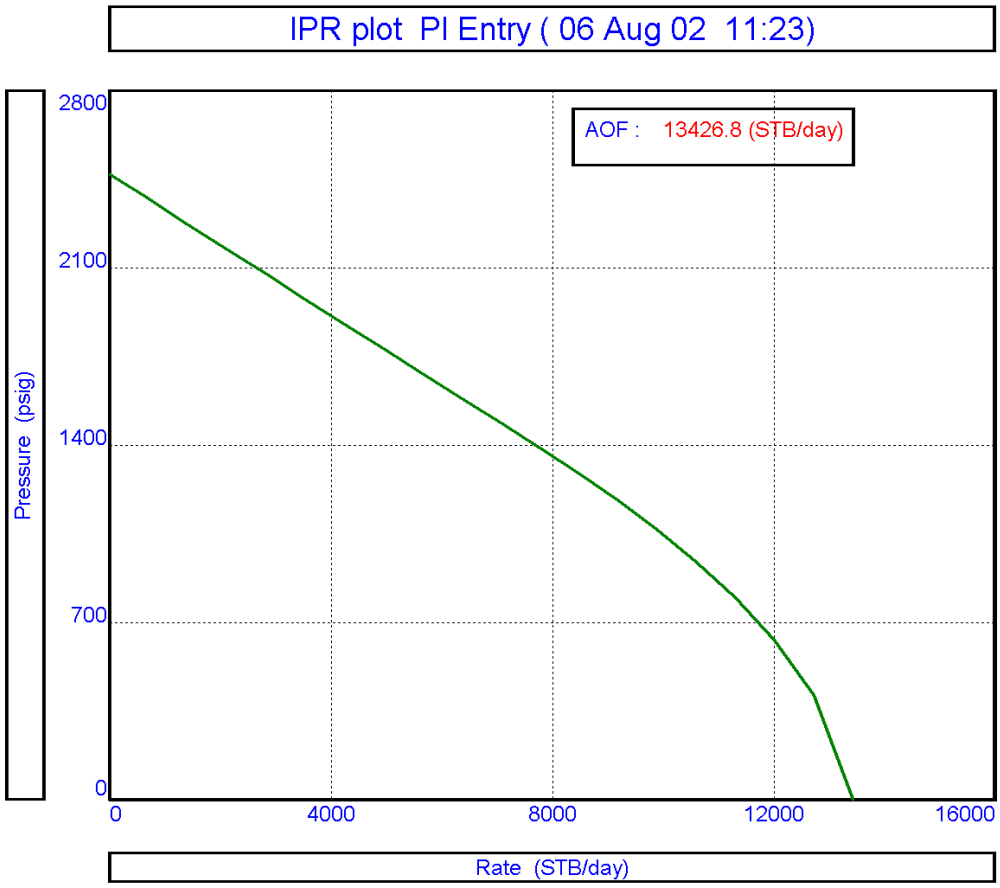


Figure 114: IPR plot

3.2.2 Matching Test Data and Data Quality Check Methods

The first thing that we will do is to try to quality check our data. Let us try to use data set 1 defined at the start of the tutorial.

At this point let us recall that for ESP models for standard traverse calculations, **PROSPER** takes the sand face as the first node for calculations. But in our test data we have a wellhead pressure as reference and do not know our bottom hole pressure. The other fact is that our test point is above the ESP, and for flow correlations, in the tubing above ESP the flow is like natural flow but with a higher bottom hole pressure. This is why, when building the basic model, we did not select the ESP pump option.

After matching we can revert to ESP option.

Always considering no artificial lift (by selecting the **None** option for the **Artificial Lift Method** in the **Options** dialog), the first step would be to check how this test point compares to the gradient plot. Select the **Matching | Correlation Comparison | Tubing** menu item and supply the following data, selecting correlations as highlighted.

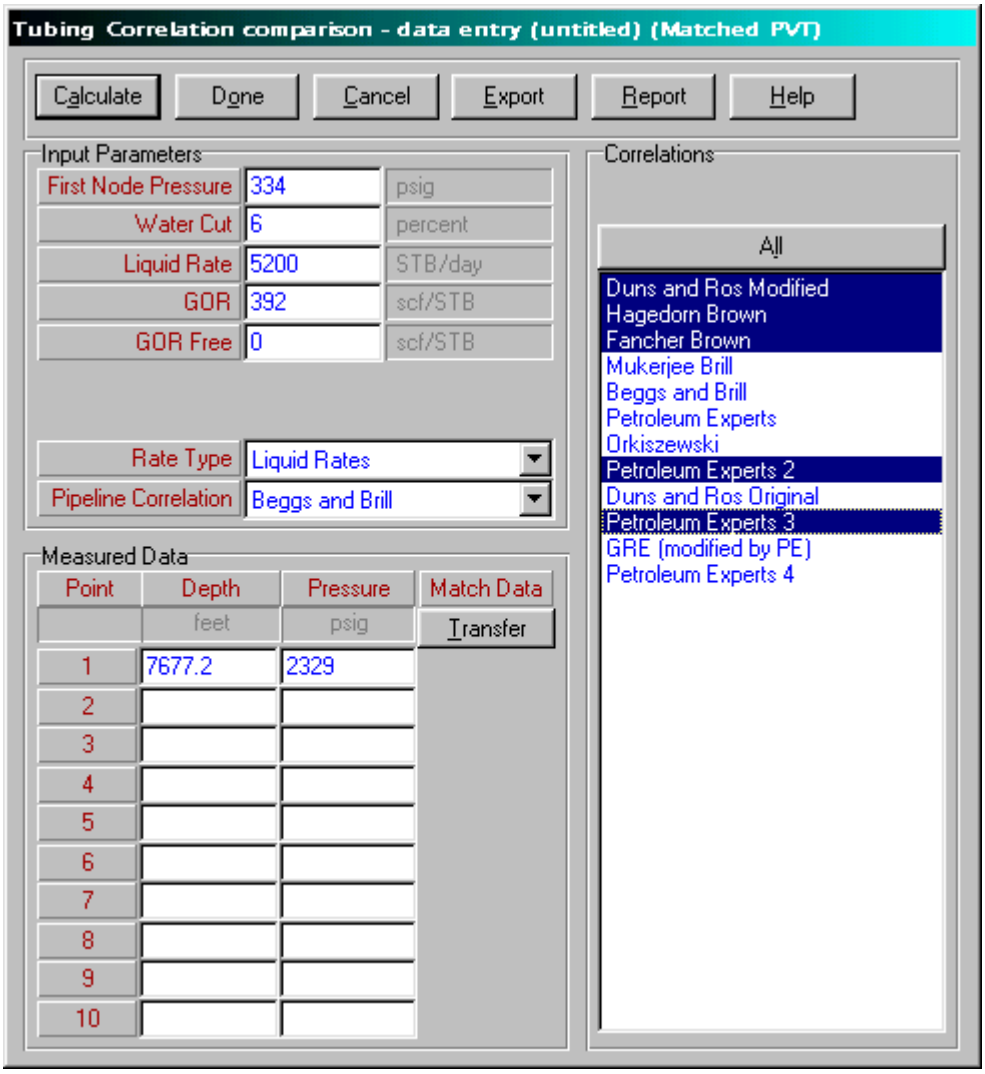


Figure 115: Correlation comparison

Once we perform calculations (by clicking the **Calculate** button and then the **Calculate** button again on the next dialog) and plot the results (by clicking the **Plot** button), we get the following plot:

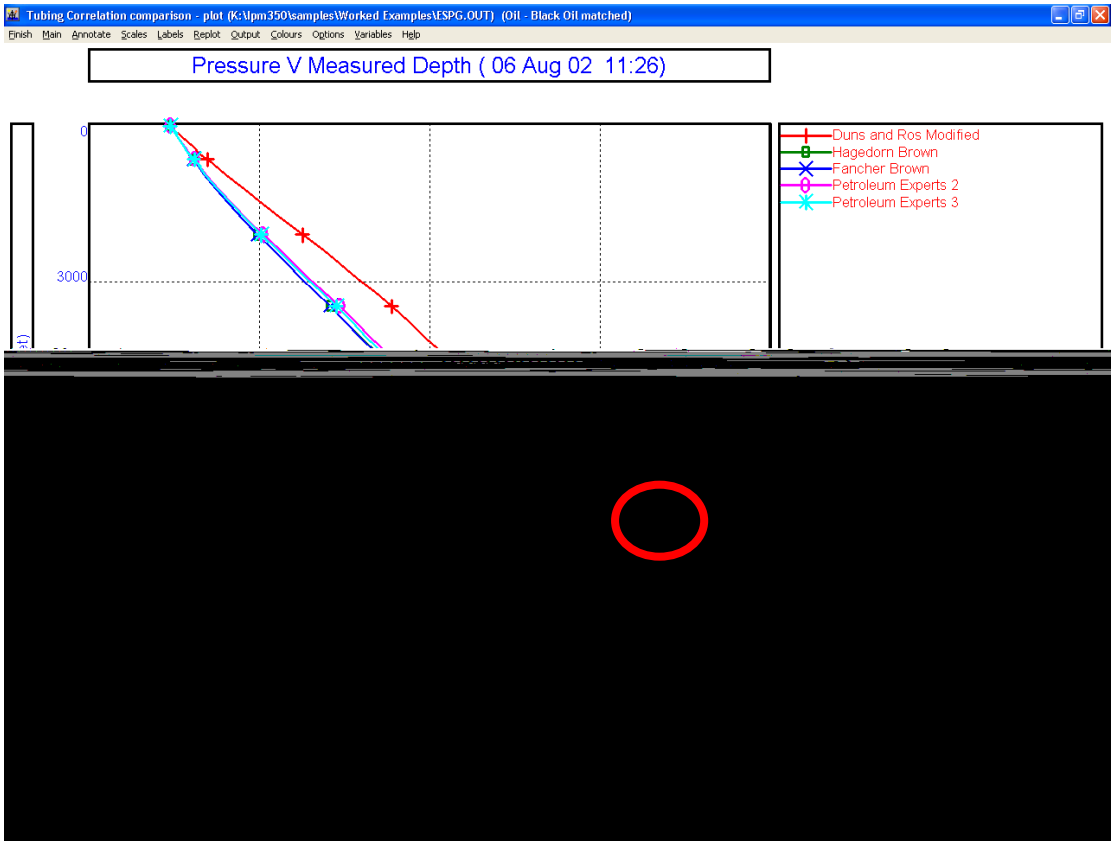

Tubing Correlation comparison - plot (K:\lpm350\samples\Worked Examples\ESPG.OUT) (Oil - Black Oil matched)
Finish Main Annotate Scales Labels Replot Output Colours Options Variables Help
Pressure V Measured Depth (06 Aug 02 11:26)
0
3000
Duns and Ros Modified
Hagedorn Brown
Fancher Brown
Petroleum Experts 2
Petroleum Experts 3

Figure 116: Gradient plot

Figure 116 shows that in the region at the bottom right of the plot, the test data point lies on the right of the Pressure traverse generated by the Duns and Ros Modified (DRM) correlation.

Now DRM correlation gives maximum pressure drop as already discussed in the previous gas lift example. But since the plot indicates that our test point requires higher pressure drop than DRM, there is something wrong. This means that the **PVT** model we have and the test data are in conflict. One of the two sets of information is incorrect. However, in this case let us say we know that our **PVT** data is correct so there are inconsistencies in the test point. The first thing that we can do is go back to the source of the test data and check again for the numbers. In this case we are reporting a water cut of 6% which is quite low for normal cases where we are thinking of going to artificial lift. As a matter of fact the water cut in this example is 34%. If we make this change to the input data of the Tubing Correlation Comparison and repeat the correlation comparison we get the following plot:

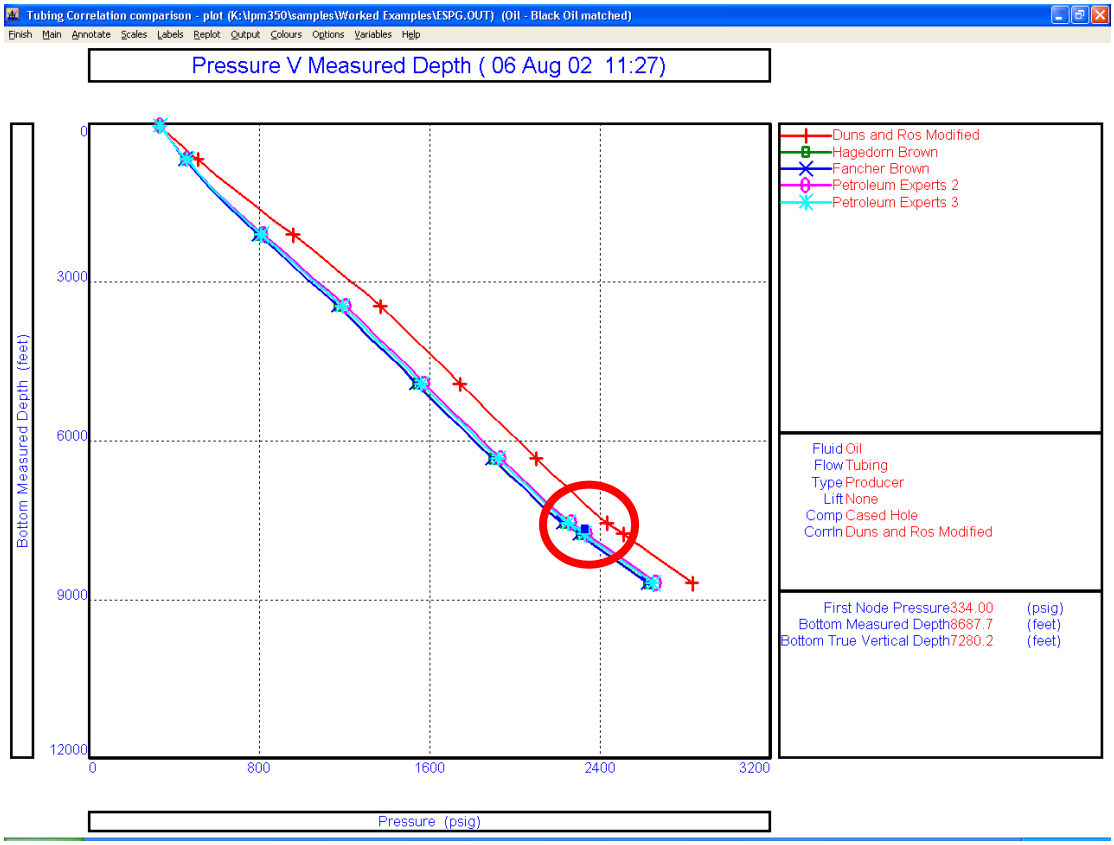


Figure 117: Gradient plot 2

Once this change is made the test data point does fall on the left of DRM correlation, and we can proceed with the use of this test data point.

The next step in building the model will be matching a correlation to the test data that we have. The matching process consists in reproducing the test data point by matching the two components of pressure drop i.e. gravity and friction by using multipliers (parameter 1 and parameter 2) for each correlation. The correlation that matches best will be selected to model flow in the tubing. Select the menu item **Matching | Matching | IPR/VLP (Quality Check)** and enter test data 1 in the screen as shown below (note that we will now use 34% for the water cut rather than the 6% in the original data):

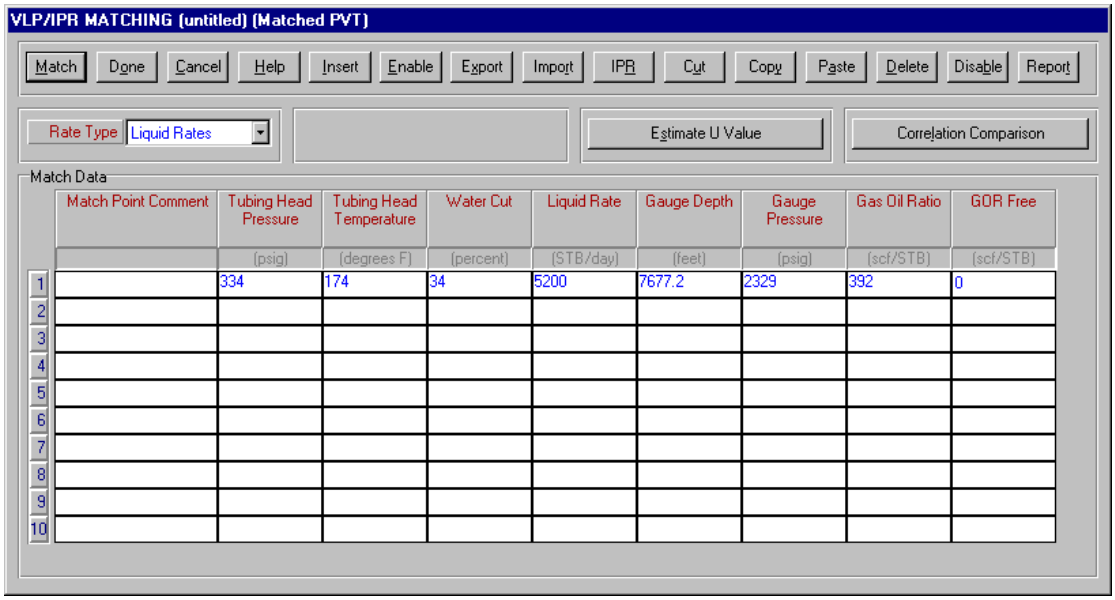
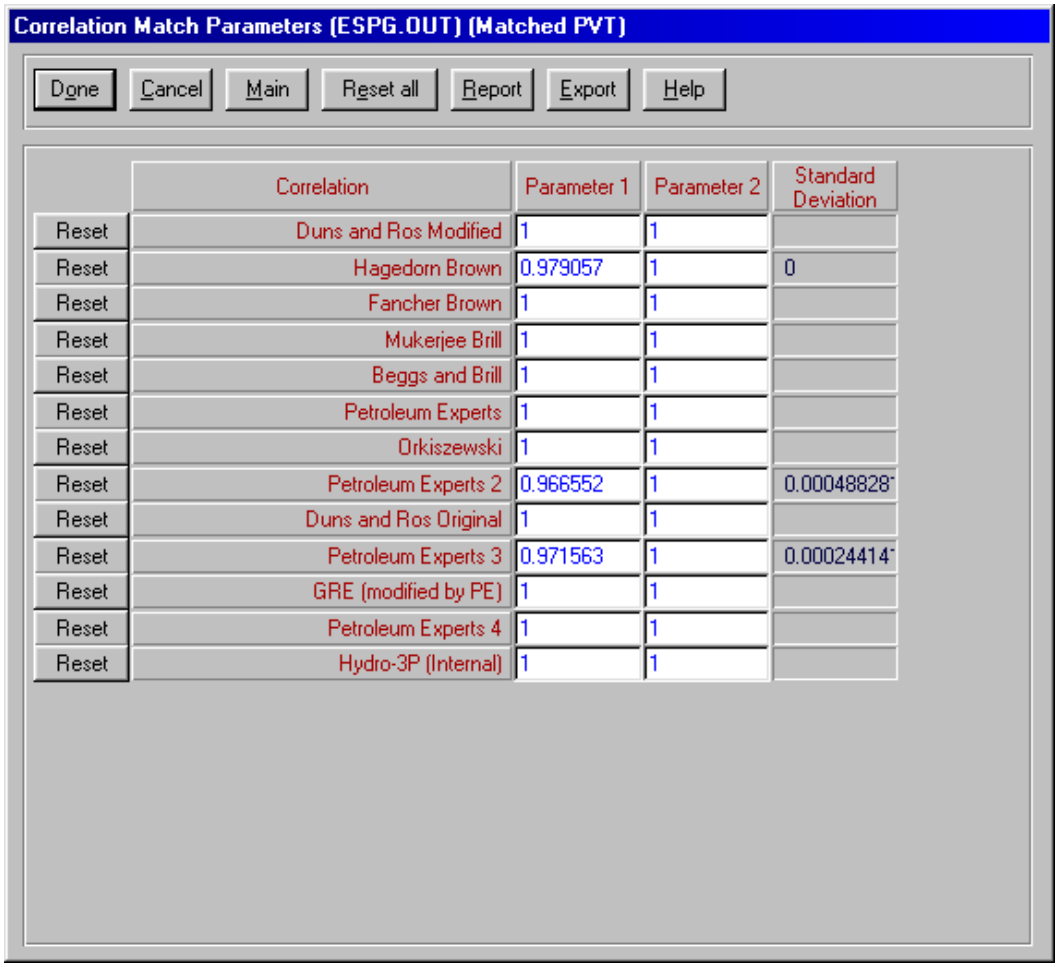


Figure 118: VLP/IPR matching data

Then perform matching by clicking the **Match** button. Select the following correlations from the list:

- Hagedorn Brown
- *Petroleum Experts* 2
- *Petroleum Experts* 3

Then click the **Match** button again to calculate the match parameters. Once we have performed the match calculations, the new match parameters (seen by pressing the **Statistics** button) are:



	Correlation	Parameter 1	Parameter 2	Standard Deviation
Reset	Duns and Ros Modified	1	1	
Reset	Hagedorn Brown	0.979057	1	0
Reset	Fancher Brown	1	1	
Reset	Mukerjee Brill	1	1	
Reset	Beggs and Brill	1	1	
Reset	Petroleum Experts	1	1	
Reset	Orkiszewski	1	1	
Reset	Petroleum Experts 2	0.966552	1	0.00048828
Reset	Duns and Ros Original	1	1	
Reset	Petroleum Experts 3	0.971563	1	0.00024414
Reset	GRE (modified by PE)	1	1	
Reset	Petroleum Experts 4	1	1	
Reset	Hydro-3P (Internal)	1	1	

Figure 119: VLP matched parameters

We are using *Petroleum Experts* 2 as the vertical lift correlation – note that we will make the selection later in the tutorial so make a note of which one to use. This finishes our matching test data and data quality check section. At the end of this save the file as **espg.out.** At this stage remember to change the lift method to ESP in the option screen.

3.2.3 Designing an ESP for this Problem

Note: We will design for a water cut of 60% and a delivering a design rate of 9000 STB/day against a wellhead pressure of 100 psig. We want the pump placed at a depth of 7660 feet. A cable roughly around 7710 feet will be needed to go up to the pump.

Select on the main screen menu **Design | ESP | Design**.
After entering the tubing outside diameters in the Downhole Equipment screen, supply the following input data. We will start with the assumption that no gas separation is needed at the pump inlet.

Pump depth	7660 ft
Operating frequency	60 Hz
Maximum OD	6 in
Length of cable	7710 ft
Gas separator efficiency	0 %
Design rate	9000 stb/day
Water cut	60 %
Top node pressure	100 psig
Motor power safety margin	0 %
Pump wear factor	0
Pipe correlation	Beggs and Brill
Tubing corrlation	*Petroleum Experts* 2

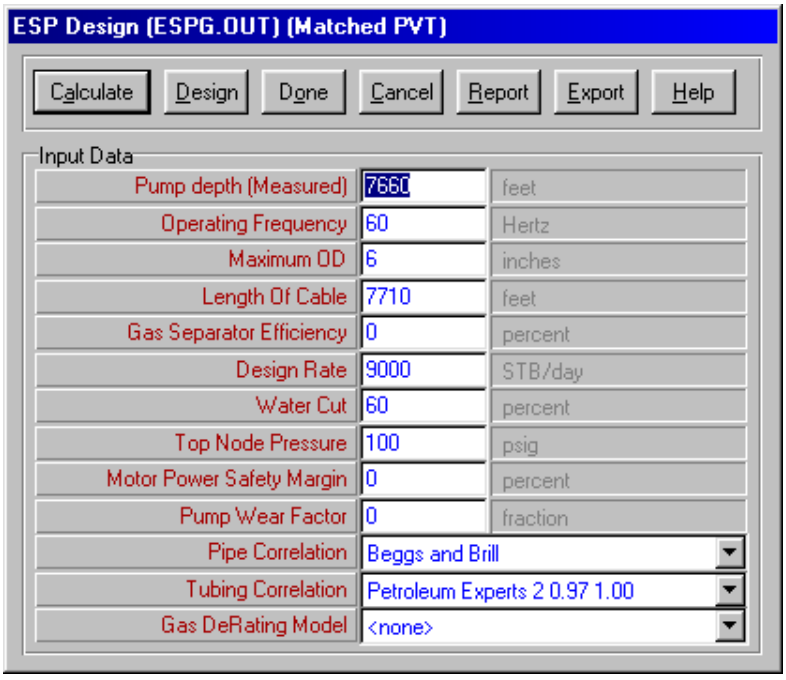


Figure 120: ESP design parameter

Press the **Calculate** button on the above dialog and the **Calculate** button again on the next dialog and **PROSPER** will calculate the pump head, power etc as shown below:

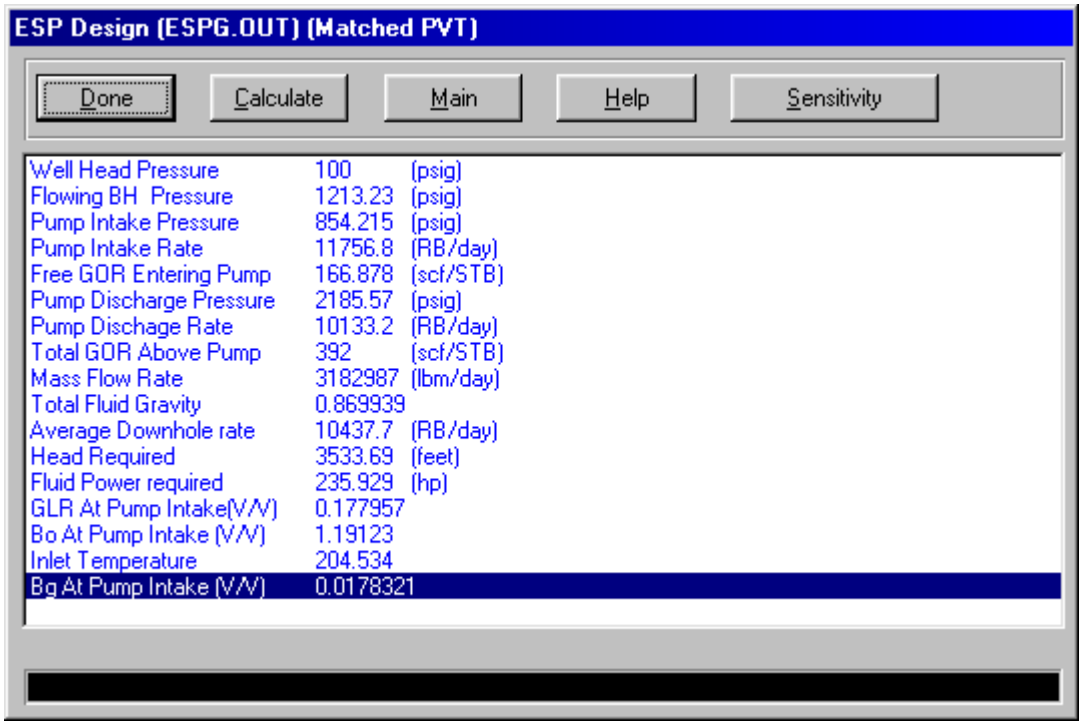

ESP Design (ESPG.OUT) (Matched PVT)
Done
Calculate
Main
Help
Sensitivity
Well Head Pressure 100 (psig)
Flowing BH Pressure 1213.23 (psig)
Pump Intake Pressure 854.215 (psig)
Pump Intake Rate 11756.8 (RB/day)
Free GOR Entering Pump 166.878 (scf/STB)
Pump Discharge Pressure 2185.57 (psig)
Pump Dischage Rate 10133.2 (RB/day)
Total GOR Above Pump 392 (scf/STB)
Mass Flow Rate 3182987 (lbm/day)
Total Fluid Gravity 0.869939
Average Downhole rate 10437.7 (RB/day)
Head Required 3533.69 (feet)
Fluid Power required 235.929 (hp)
GLR At Pump Intake(V/V) 0.177957
Bo At Pump Intake (V/V) 1.19123
Inlet Temperature 204.534
Bg At Pump Intake (V/V) 0.0178321

Figure 121: ESP design calculation

Once pump calculations are finished, check the validity of the assumption of no gas separation at pump inlet by using the Dunbar plot. The plot is activated by pressing the **Sensitivity** button and the following plot appears:

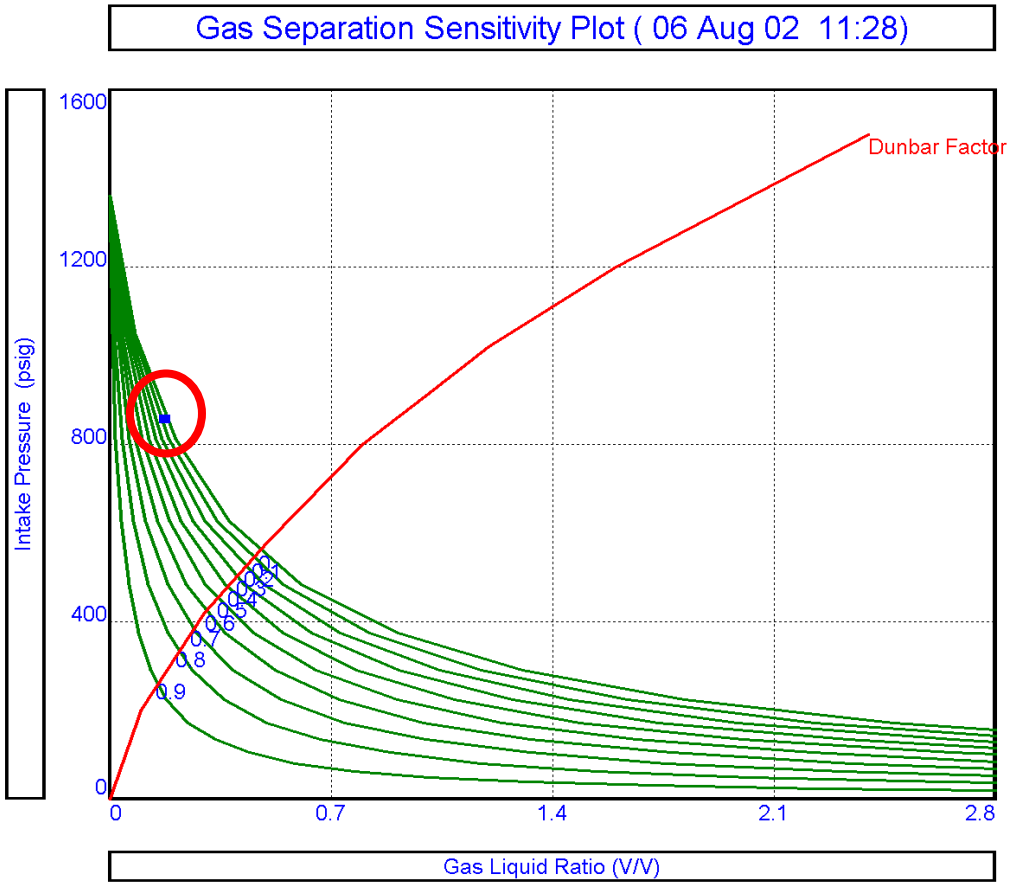


Figure 122: Sensitivity plot

The different lines on the Dunbar plot are for different levels of gas separation efficiency at pump intake. The separation efficiency assumed is okay for this criterion if it the point of operation falls above the Dunbar line. In this case, the pump operating point with zero separation at inlet (shown by the square symbol) falls above the Dunbar line, which implies that we do not need a gas separator at the pump inlet. In case it was otherwise, we should use a separation efficiency in the ESP Design input dialog above and repeat the pump calculations until we get the pump intake point above the Dunbar line.

After checking for gas separation requirements, we proceed with the design by pressing the **Finish** button on the plot, the **Done** button followed by the **Design** button and we should be in the following dialog:

The design at this stage consists in determining an adequate pump, motor and cable that can handle this load.

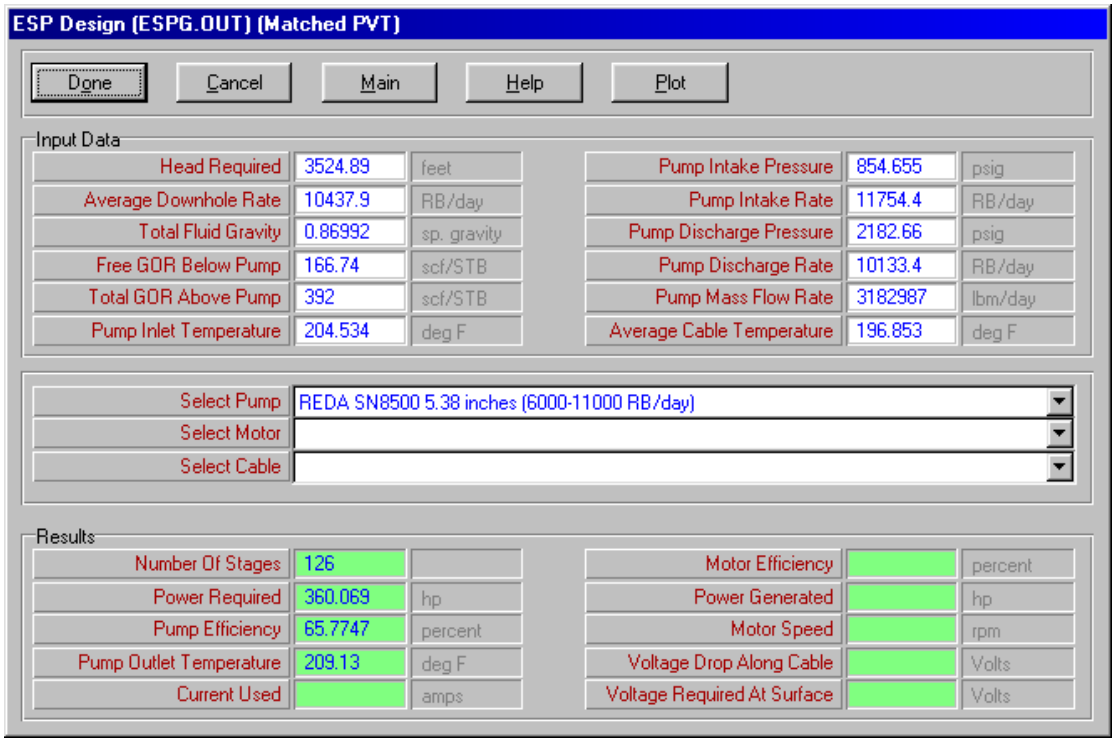
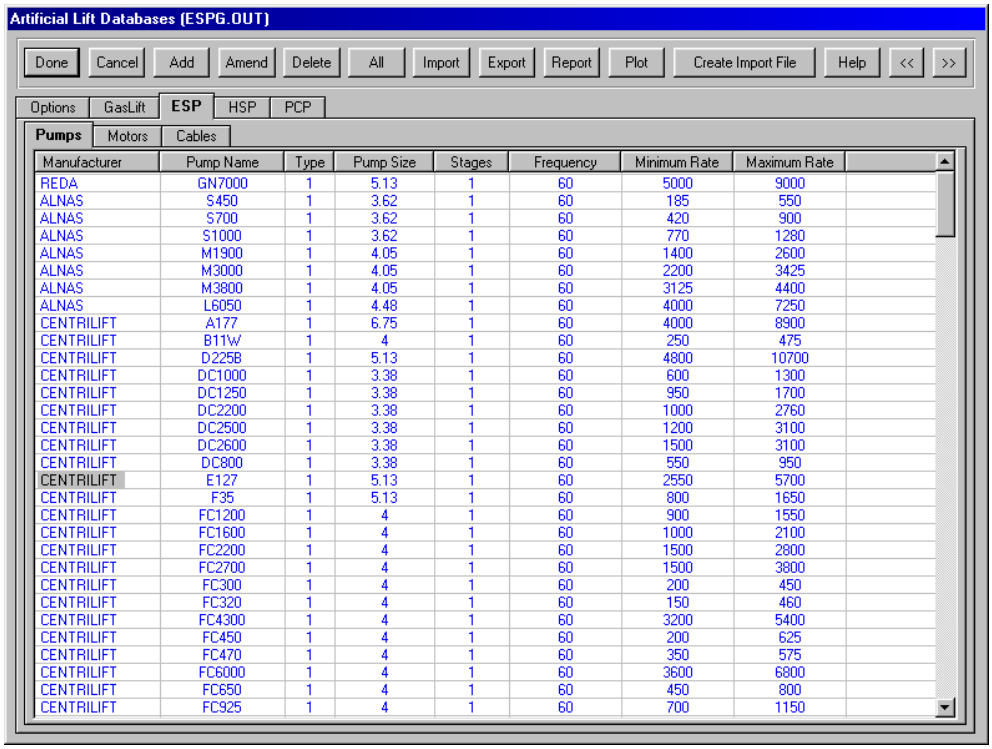


Figure 123: Selecting the suitable pump, motor, and cable

Note that you should have built your pump, motor and cable database by now. If you have not, go to **Design | ESP | Pump database** and you will get the following screen:



Manufacturer	Pump Name	Type	Pump Size	Stages	Frequency	Minimum Rate	Maximum Rate
REDA	GN7000	1	5.13	1	60	5000	9000
ALNAS	S450	1	3.62	1	60	185	550
ALNAS	S700	1	3.62	1	60	420	900
ALNAS	S1000	1	3.62	1	60	770	1280
ALNAS	M1900	1	4.05	1	60	1400	2600
ALNAS	M3000	1	4.05	1	60	2200	3425
ALNAS	M3800	1	4.05	1	60	3125	4400
ALNAS	L6050	1	4.48	1	60	4000	7250
CENTRILIFT	A177	1	6.75	1	60	4000	8900
CENTRILIFT	B11W	1	4	1	60	250	475
CENTRILIFT	D225B	1	5.13	1	60	4800	10700
CENTRILIFT	DC1000	1	3.38	1	60	600	1300
CENTRILIFT	DC1250	1	3.38	1	60	950	1700
CENTRILIFT	DC2200	1	3.38	1	60	1000	2760
CENTRILIFT	DC2500	1	3.38	1	60	1200	3100
CENTRILIFT	DC2600	1	3.38	1	60	1500	3100
CENTRILIFT	DC800	1	3.38	1	60	550	950
CENTRILIFT	E127	1	5.13	1	60	2550	5700
CENTRILIFT	F35	1	5.13	1	60	800	1650
CENTRILIFT	FC1200	1	4	1	60	900	1550
CENTRILIFT	FC1600	1	4	1	60	1000	2100
CENTRILIFT	FC2200	1	4	1	60	1500	2800
CENTRILIFT	FC2700	1	4	1	60	1500	3800
CENTRILIFT	FC300	1	4	1	60	200	450
CENTRILIFT	FC320	1	4	1	60	150	460
CENTRILIFT	FC4300	1	4	1	60	3200	5400
CENTRILIFT	FC450	1	4	1	60	200	625
CENTRILIFT	FC470	1	4	1	60	350	575
CENTRILIFT	FC6000	1	4	1	60	3600	6800
CENTRILIFT	FC650	1	4	1	60	450	800
CENTRILIFT	FC925	1	4	1	60	700	1150

Figure 124: Editing the pump database

On this screen use **Import | Append** to import a pump database. There are some databases provided with the program in the \samples**PROSPER** directory. You can load the motor and cable databases in a similar fashion.

The design screen will select from the database, the equipment that can do the job. We will select one combination out of these. In the first selection we select the pump, then the motor and finally the cable.

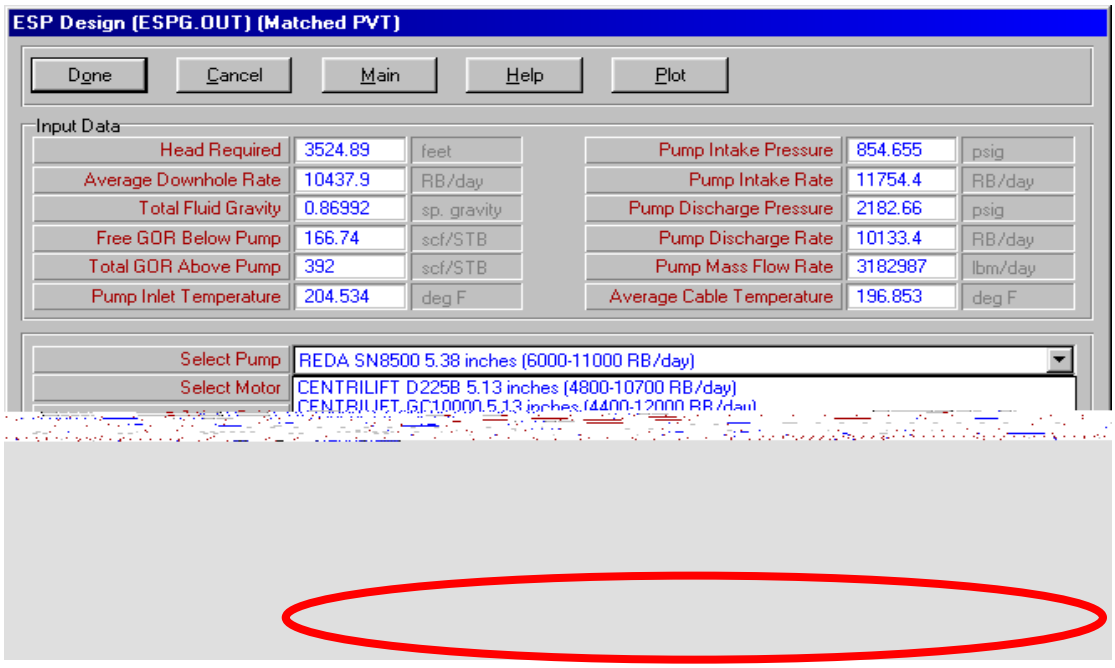

ESP Design (ESPG.OUT) (Matched PVT)
Done
Cancel
Main
Help
Plot
Input Data
Head Required 3524.89 feet
Average Downhole Rate 10437.9 RB/day
Total Fluid Gravity 0.86992 sp. gravity
Free GOR Below Pump 166.74 scf/STB
Total GOR Above Pump 392 scf/STB
Pump Inlet Temperature 204.534 deg F
Pump Intake Pressure 854.655 psig
Pump Intake Rate 11754.4 RB/day
Pump Discharge Pressure 2182.66 psig
Pump Discharge Rate 10133.4 RB/day
Pump Mass Flow Rate 3182987 lbm/day
Average Cable Temperature 196.853 deg F
Select Pump REDA SN8500 5.38 inches (6000-11000 RB/day)
Select Motor CENTRILIFT D225B 5.13 inches (4800-10700 RB/day)

Figure 125: Selecting pump

From the available pumps, let us select the **REDA SN8500** model. Next we will select a motor for this pump as shown below:

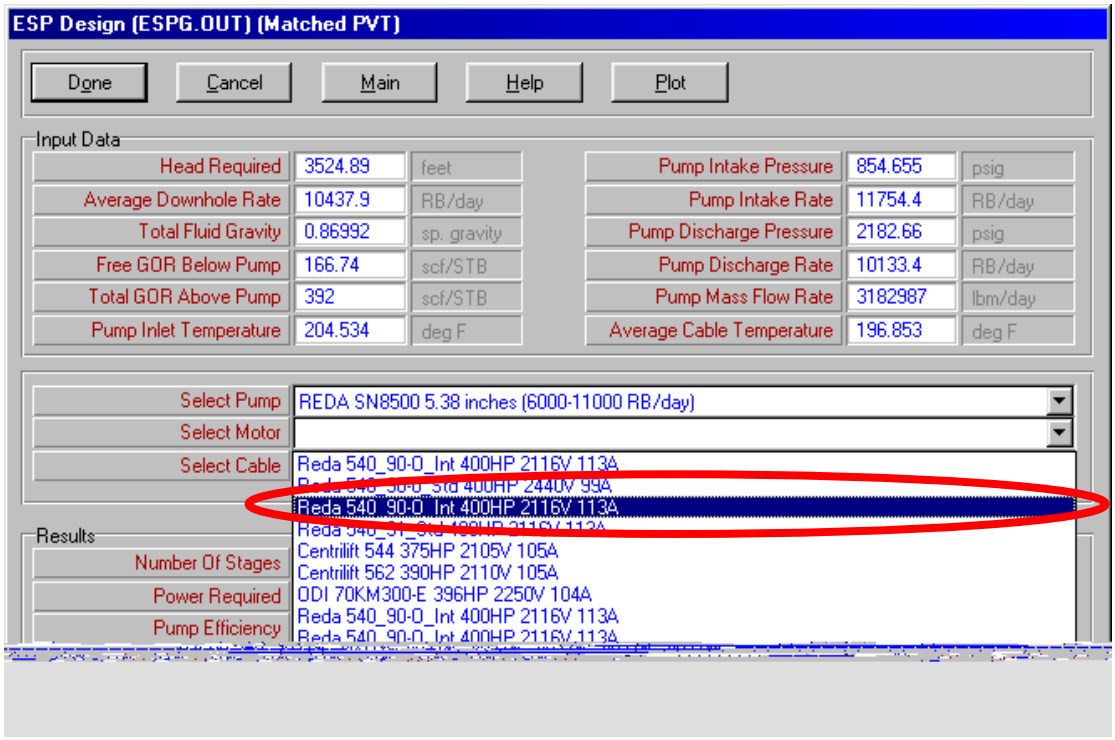

ESP Design (ESPG.OUT) (Matched PVT)
Done
Cancel
Main
Help
Plot
Input Data
Head Required 3524.89 feet
Average Downhole Rate 10437.9 RB/day
Total Fluid Gravity 0.86992 sp. gravity
Free GOR Below Pump 166.74 scf/STB
Total GOR Above Pump 392 scf/STB
Pump Inlet Temperature 204.534 deg F
Pump Intake Pressure 854.655 psig
Pump Intake Rate 11754.4 RB/day
Pump Discharge Pressure 2182.66 psig
Pump Discharge Rate 10133.4 RB/day
Pump Mass Flow Rate 3182987 lbm/day
Average Cable Temperature 196.853 deg F
Select Pump REDA SN8500 5.38 inches (6000-11000 RB/day)
Select Motor
Select Cable
Reda 540_90-0_Int 400HP 2116V 113A
Reda 540_90-0_Std 400HP 2440V 99A
Reda 540_90-0_Int 400HP 2116V 113A
Centrilift 544 375HP 2105V 105A
Centrilift 562 390HP 2110V 105A
ODI 70KM300-E 396HP 2250V 104A
Reda 540_90-0_Int 400HP 2116V 113A
Results
Number Of Stages
Power Required
Pump Efficiency

Figure 126: Selecting motor

From the motor selection let us select the **Reda 540_90-0_Int 400HP 2116V 113A** motor. Next we will select a cable from the possible ones.

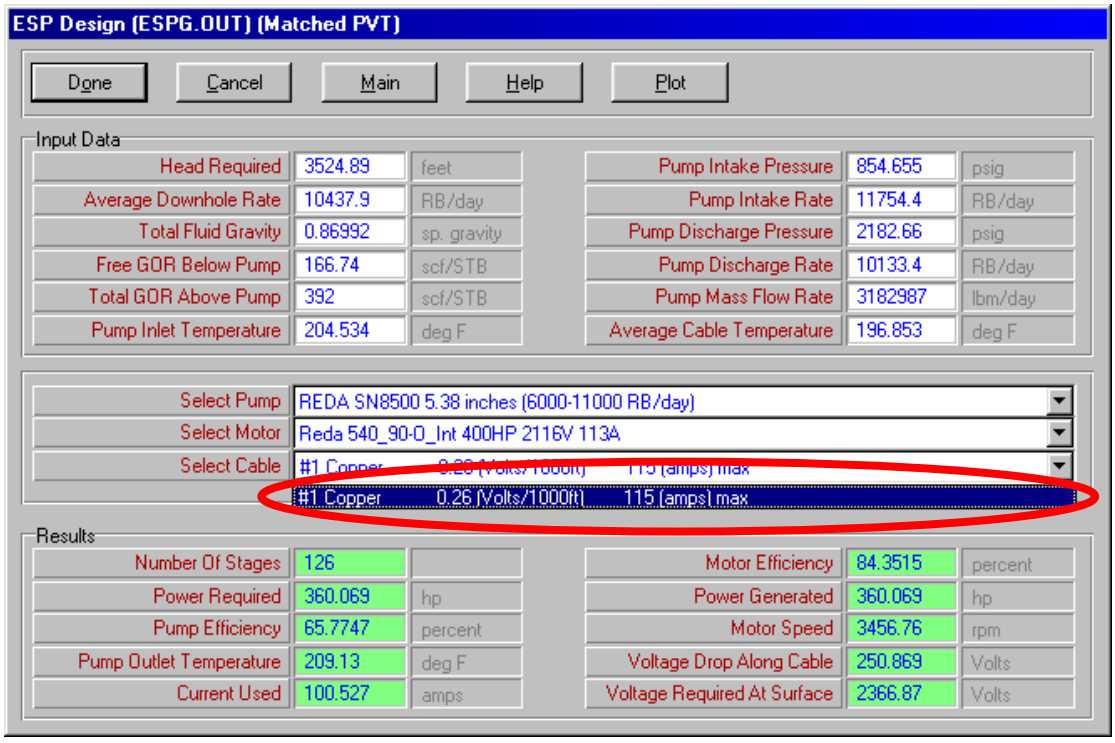

ESP Design (ESPG.OUT) (Matched PVT)
Done
Cancel
Main
Help
Plot
Input Data
Head Required 3524.89 feet
Average Downhole Rate 10437.9 RB/day
Total Fluid Gravity 0.86992 sp. gravity
Free GOR Below Pump 166.74 scf/STB
Total GOR Above Pump 392 scf/STB
Pump Inlet Temperature 204.534 deg F
Pump Intake Pressure 854.655 psig
Pump Intake Rate 11754.4 RB/day
Pump Discharge Pressure 2182.66 psig
Pump Discharge Rate 10133.4 RB/day
Pump Mass Flow Rate 3182987 lbm/day
Average Cable Temperature 196.853 deg F
Select Pump REDA SN8500 5.38 inches (6000-11000 RB/day)
Select Motor Reda 540_90-0_Int 400HP 2116V 113A
Select Cable
#1 Copper 0.26 (Volts/1000ft) 115 (amps) max
Results
Number Of Stages 126
Power Required 360.069 hp
Pump Efficiency 65.7747 percent
Pump Outlet Temperature 209.13 deg F
Current Used 100.527 amps
Motor Efficiency 84.3515 percent
Power Generated 360.069 hp
Motor Speed 3456.76 rpm
Voltage Drop Along Cable 250.869 Volts
Voltage Required At Surface 2366.87 Volts

Figure 127: Selecting cable

Based on the selection available we select **#1 Copper** as our cable. This stage completes the ESP design and the results are displayed in the same screen in terms of current required etc as shown below:

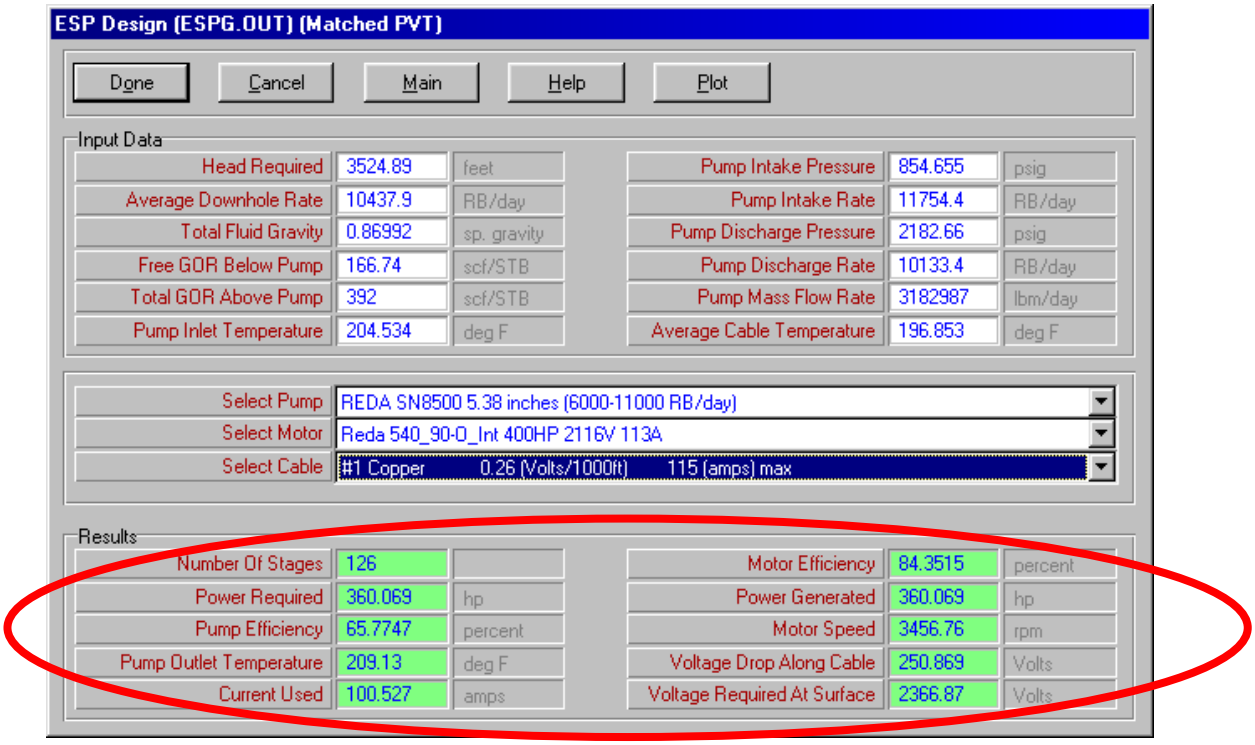

ESP Design (ESPG.OUT) (Matched PVT)
Done
Cancel
Main
Help
Plot
Input Data
Head Required 3524.89 feet
Average Downhole Rate 10437.9 RB/day
Total Fluid Gravity 0.86992 sp. gravity
Free GOR Below Pump 166.74 scf/STB
Total GOR Above Pump 392 scf/STB
Pump Inlet Temperature 204.534 deg F
Pump Intake Pressure 854.655 psig
Pump Intake Rate 11754.4 RB/day
Pump Discharge Pressure 2182.66 psig
Pump Discharge Rate 10133.4 RB/day
Pump Mass Flow Rate 3182987 lbm/day
Average Cable Temperature 196.853 deg F
Select Pump REDA SN8500 5.38 inches (6000-11000 RB/day)
Select Motor Reda 540_90-0_Int 400HP 2116V 113A
Select Cable #1 Copper 0.26 (Volts/1000ft) 115 (amps) max
Results
Number Of Stages 126
Power Required 360.069 hp
Pump Efficiency 65.7747 percent
Pump Outlet Temperature 209.13 deg F
Current Used 100.527 amps
Motor Efficiency 84.3515 percent
Power Generated 360.069 hp
Motor Speed 3456.76 rpm
Voltage Drop Along Cable 250.869 Volts
Voltage Required At Surface 2366.87 Volts

Figure 128: ESP design details

We have selected a REDA SN8500 pump with 126 stages to do the job. If we click on the Plot button it display the pump performance curve also indicating the limits of operation of this pump.

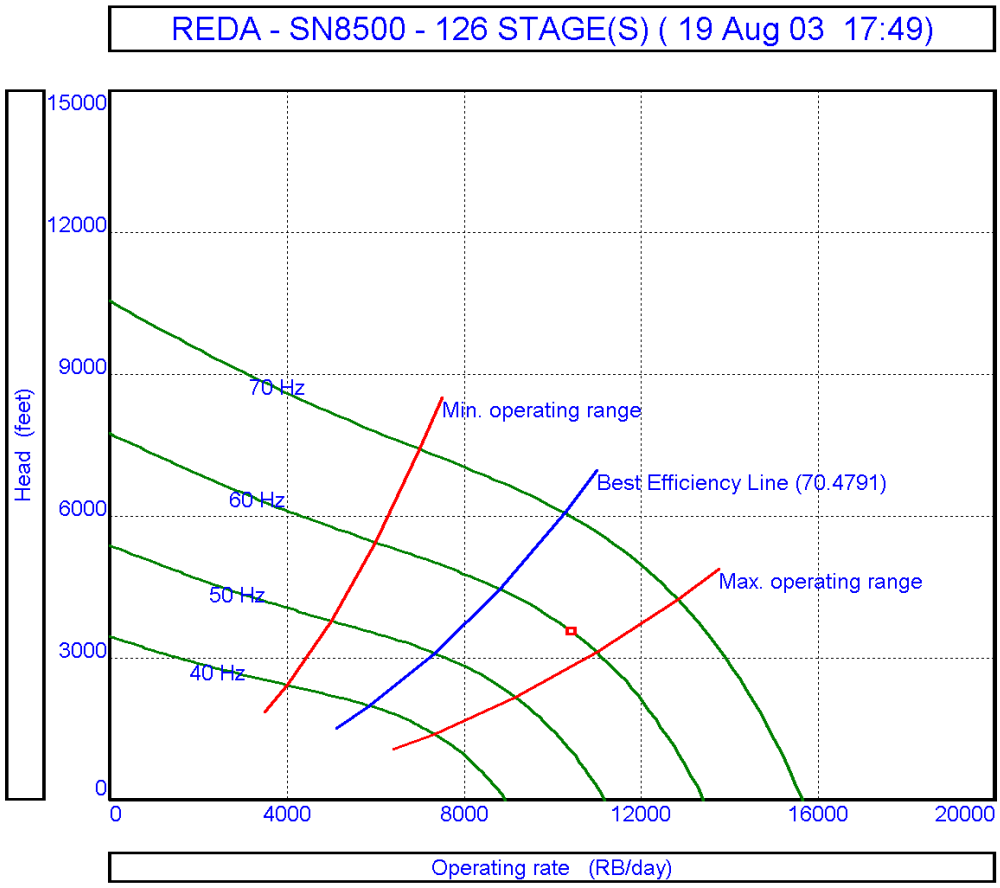


Figure 129: ESP pump plot

The point on this plot shows the design operating point on the pump performance plot. This finishes a new ESP design.

3.2.4 Using ESP QuickLook as a Diagnostic Option to check an Existing ESP Design

Note: In this section we are going to use the QuickLook option as a diagnostic tool. We will see how we can monitor the performance of an ESP for an intermediate water cut that has been designed on the basis of 60% future water. What we have is reliable down-hole measured data for pump intake and discharge pressure in this case. A liquid rate of 6523 STB/day with a well head pressure of 345 psig has been observed for this well.

We will start by selecting the menu option **Matching | QuickLook**. The measurements indicate a water cut of 60%. The pump is same as designed in the previous section. We will assume that the pump runs at 60 Hz still has no wear factor. On the basis of these measurements we can supply the data as shown below:

Tubing head pressure	345 psig
Liquid rate	6523 stb/day
Water cut	60 %
Produced GOR	392 scf/stb
Static bottom hole pressure	2468 psig
Pump depth	7660 ft
Operating frequency	60 Hz
Length of cable	7710 ft
Gas separation efficiency	0 %
Number of stages	126
Pump wear factor	0 (fraction)

Downhole data:
Pump discharge pressure (MD = 7660 ft) = 2725 psig
Pump suction pressure (MD = 7660 ft) = 1025 psig

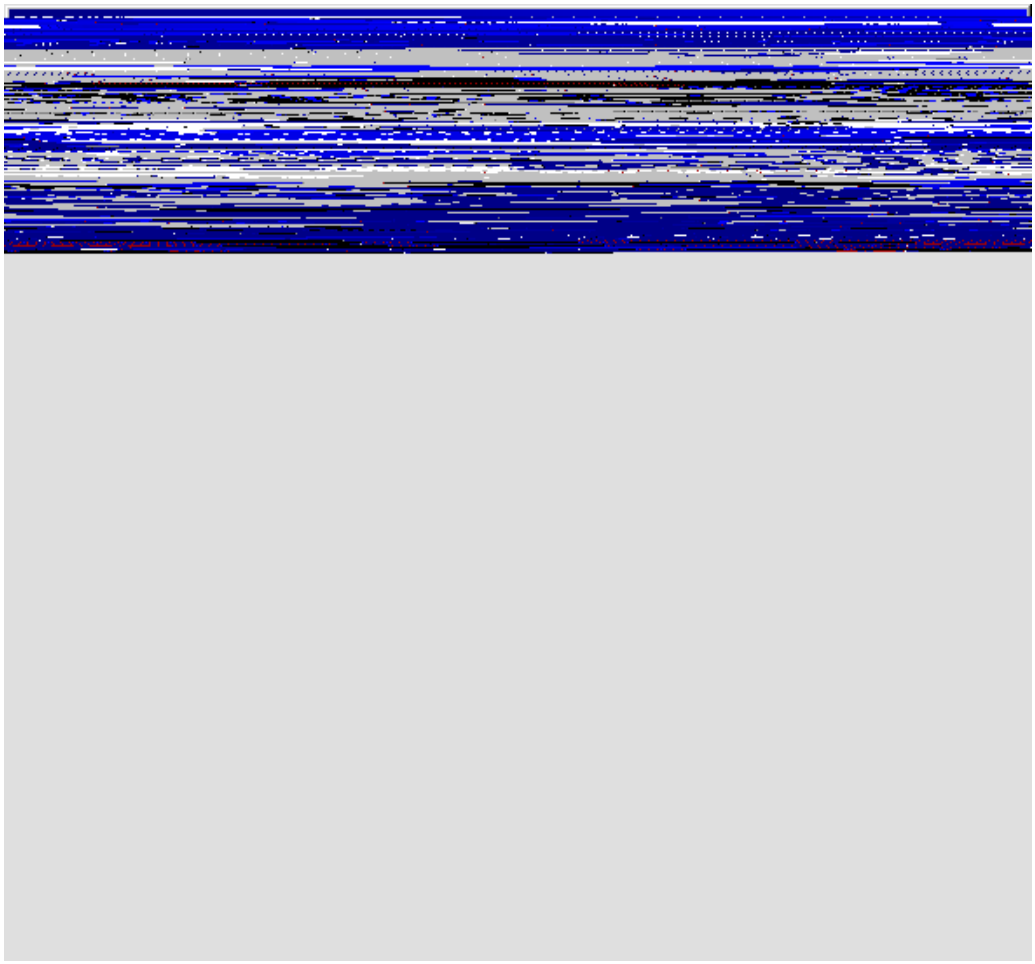


Figure 130: ESP QuickLook

Once we have given the measured pressure data and the flow rates, through the pump, to start QuickLook press the **Calculate** button, the **Calculate** button again and then the **Plot** button. You should get the following plot:

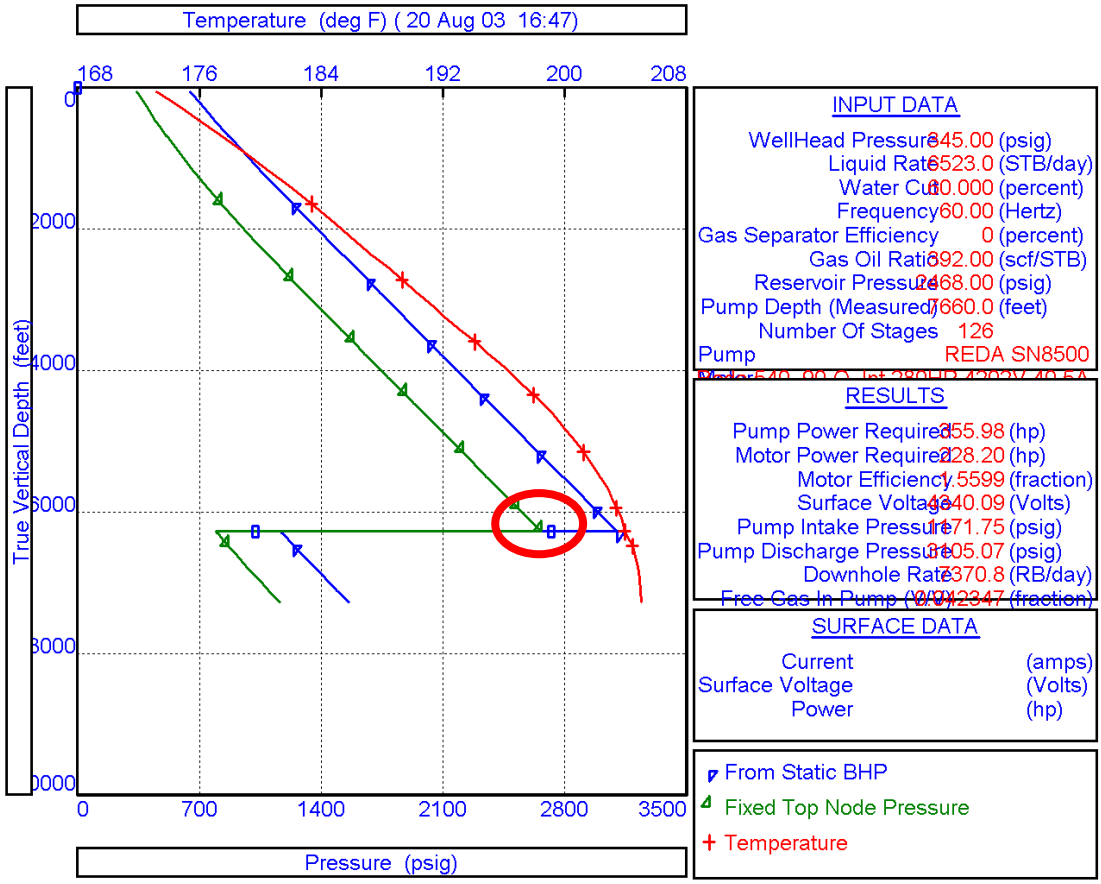


Figure 131: ESP QuickLook plot

To analyse this plot, let us examine the QuickLook principle. In this method we calculate well pressure traverses in two directions, one beginning from the well head and going to the sand-face, and the other going from the sand face up all the way to the wellhead. In case our assumptions about the pump depth and oil flows etc. are correct, the two pressure traverses should be identical and overlap. If not we have to change these assumptions until we get identical traverses.

To start the process of diagnosis, we can think of the pump as a **tie point** for the system, where the inflow up to the pump and the lift above the pump are tied with each other. For a given wellhead pressure, the pump discharge pressure depends only on the weight and frictional loss of the fluid above the pump. In our case we see that, for the measured well head pressure, the pump discharge pressure we got is slightly lower than that measured as indicated by the circle area on the above plot.
The section of the well can be considered as a naturally flowing well with bottomhole pressure equal to the pump discharge pressure.
So, in order to match the downward discharge pressure point with the measured one, we can go back to the simple well configuration (choosing No Artificial Lift from the Option screen) and tune the flow correlations using the measured data at the pump discharge as test data:

Tubing Head Pressure:	345 psig
Tubing Head Temperature:	174 deg F
Water Cut:	60 %
Liquid Rate:	6523 STB/day
Gauge Depth:	7660 ft
Gauge Pressure:	2725 psig

GOR: 392 scf/STB
GOR free: 0 scf/STB

Enter these data in the VLP/IPR Matching screen:

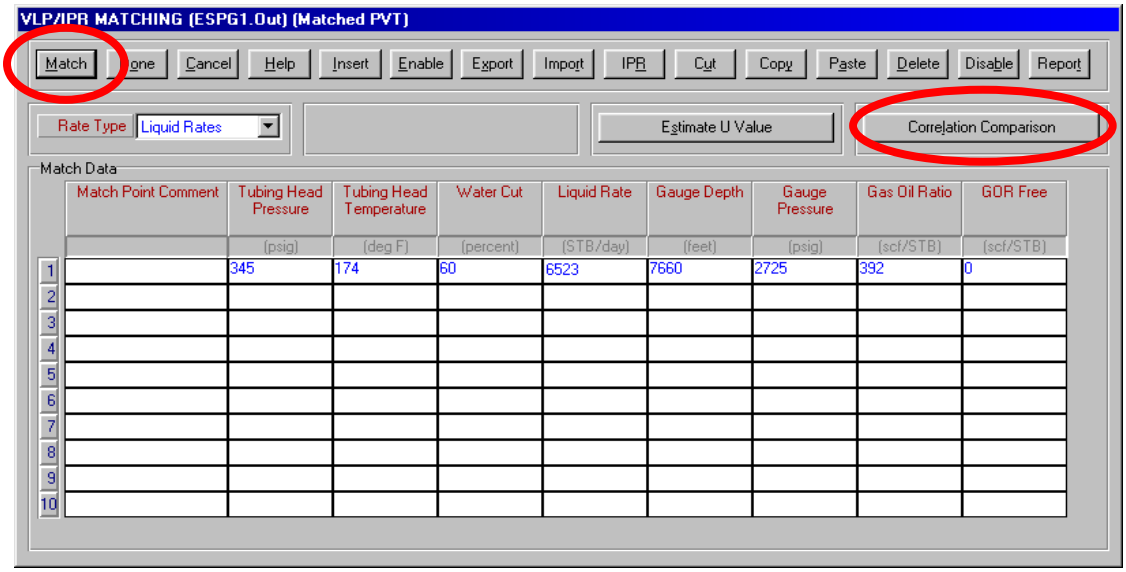


Figure 132: VLP/IPR Matching screen

Then perform the Correlation Comparison to quality check the test data. The test data point is within the limits given by the Duns and Ros Modified and Fancher and Brown correlations, as shown in the following plot:

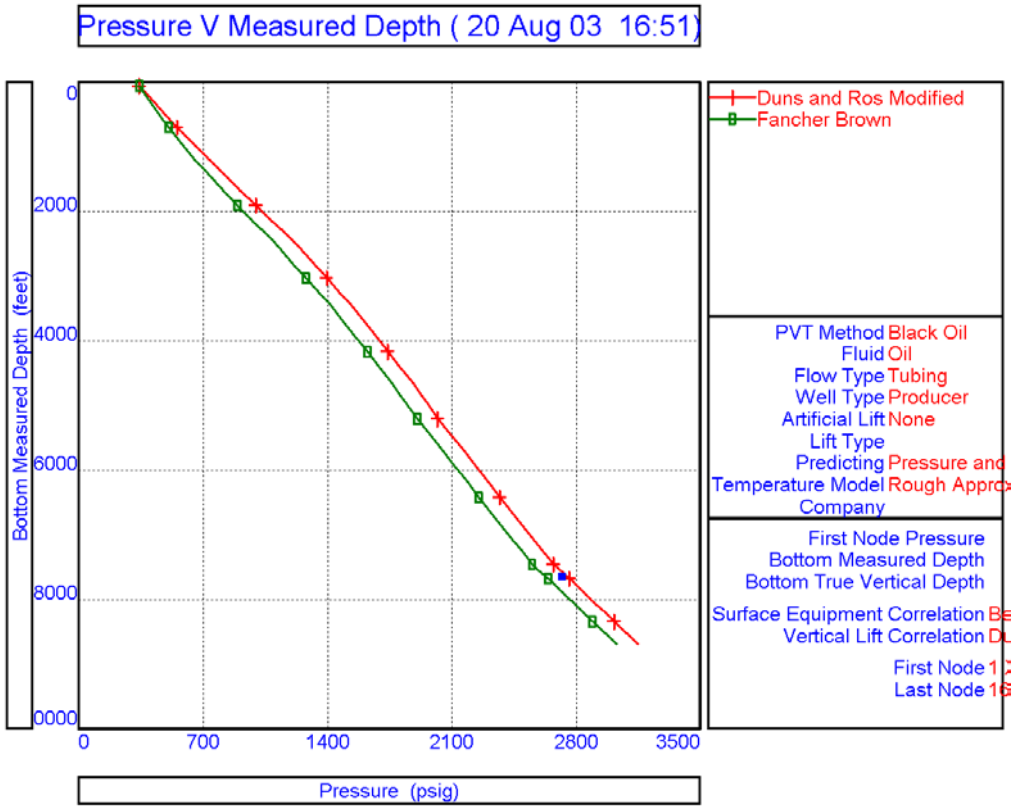


Figure 133: Correlation Comparison

The choice of the correlation is done following the guidelines given by the **PROSPER** manual.
Now, back in the VLP/IPR screen, we click on Match, choose the Petroleum Experts 2 correlation and click on Match again.

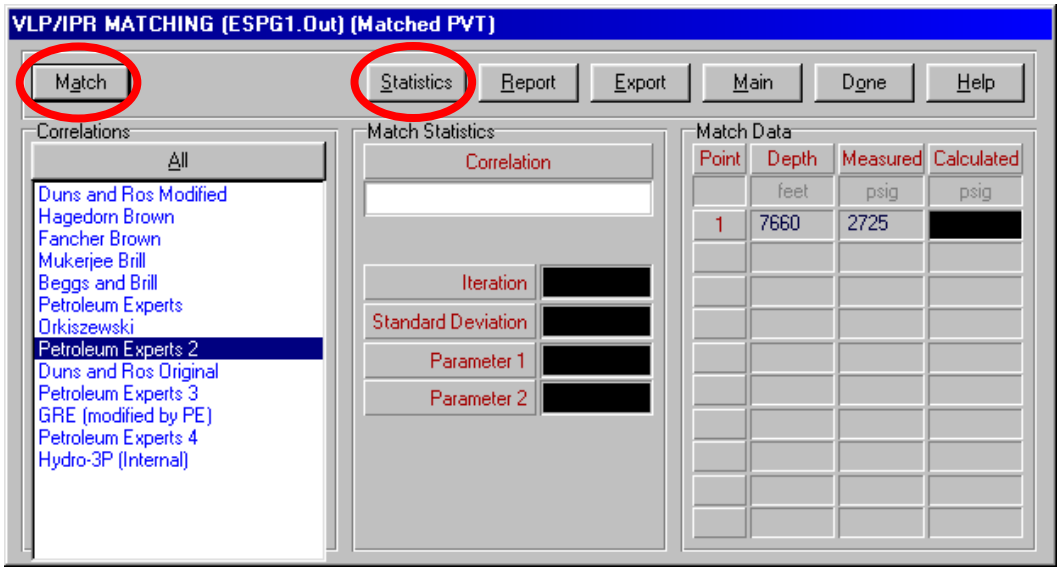


Figure 134: VLP/IPR Matching

The match parameters are calculated. Clicking on Statistics, the match parameters are displayed:

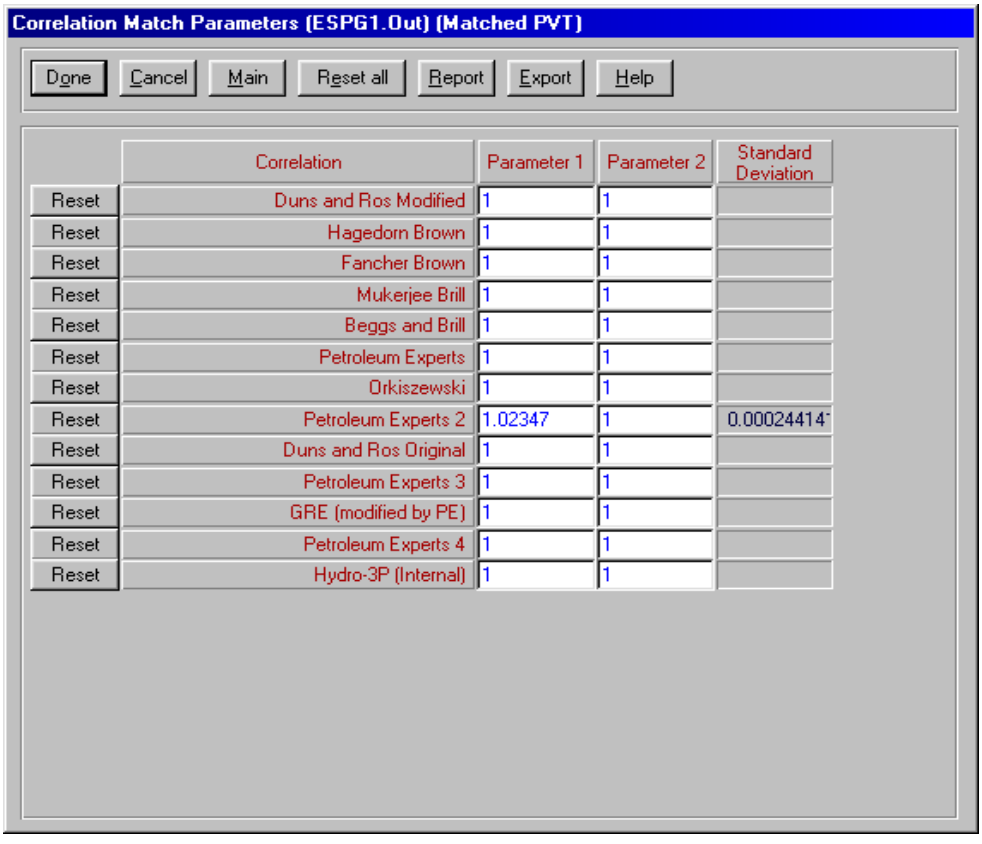


Figure 135: Match parameters

At this point, it is possible to re-select the ESP Artificial Lift Method from the Option menu and go to the QuickLook section.
Click on Calculate | Calculate, then Plot. The following QuickLook plot is displayed:

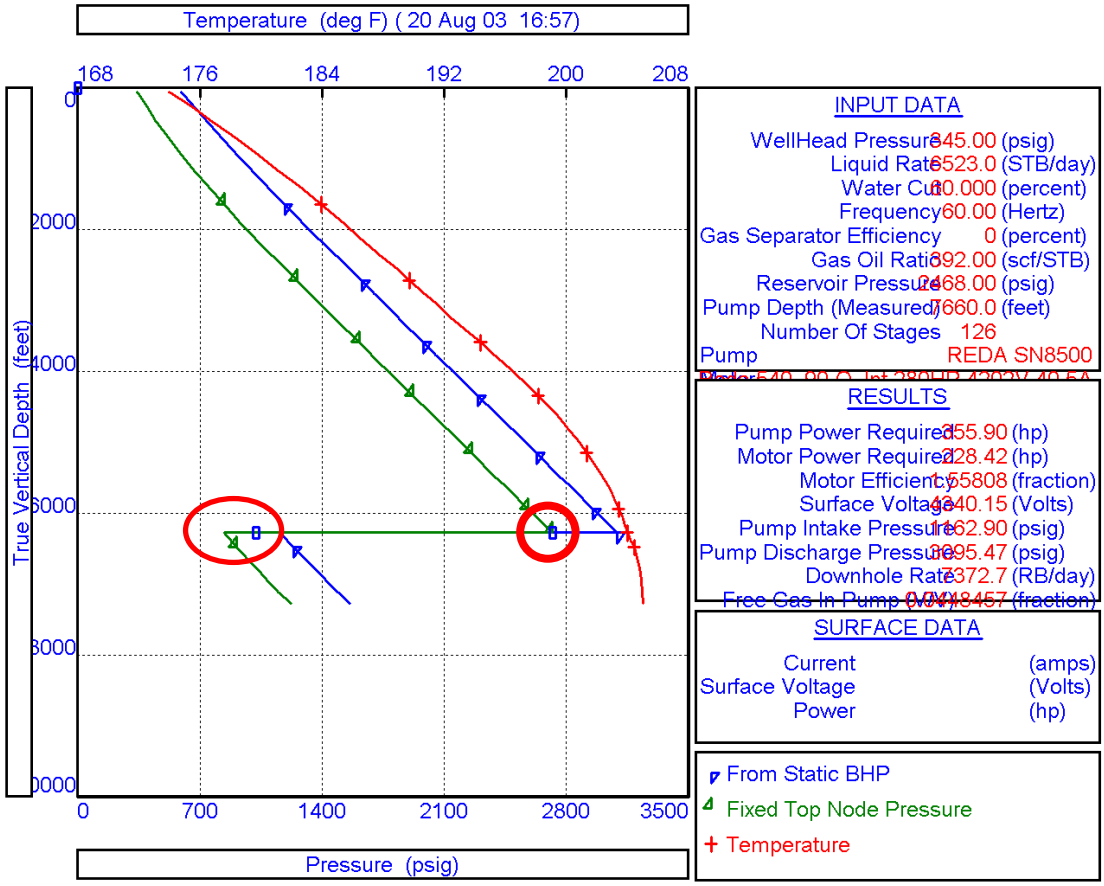


Figure 136: ESP QuickLook plot

As it is shown, now the discharge pressure point on the measured downward gradient is matched.
Now the pump inlet pressure must be matched. **Figure 136** shows that the dP across the pump calculated in the downward gradient is bigger than the measure one (given by the distance between the two blue squares). The reason of this could be, for example, the pump wear, which decreases the pump performance.
So, let's choose a pump wear factor of 0.11 to be entered in the QuickLook main screen:

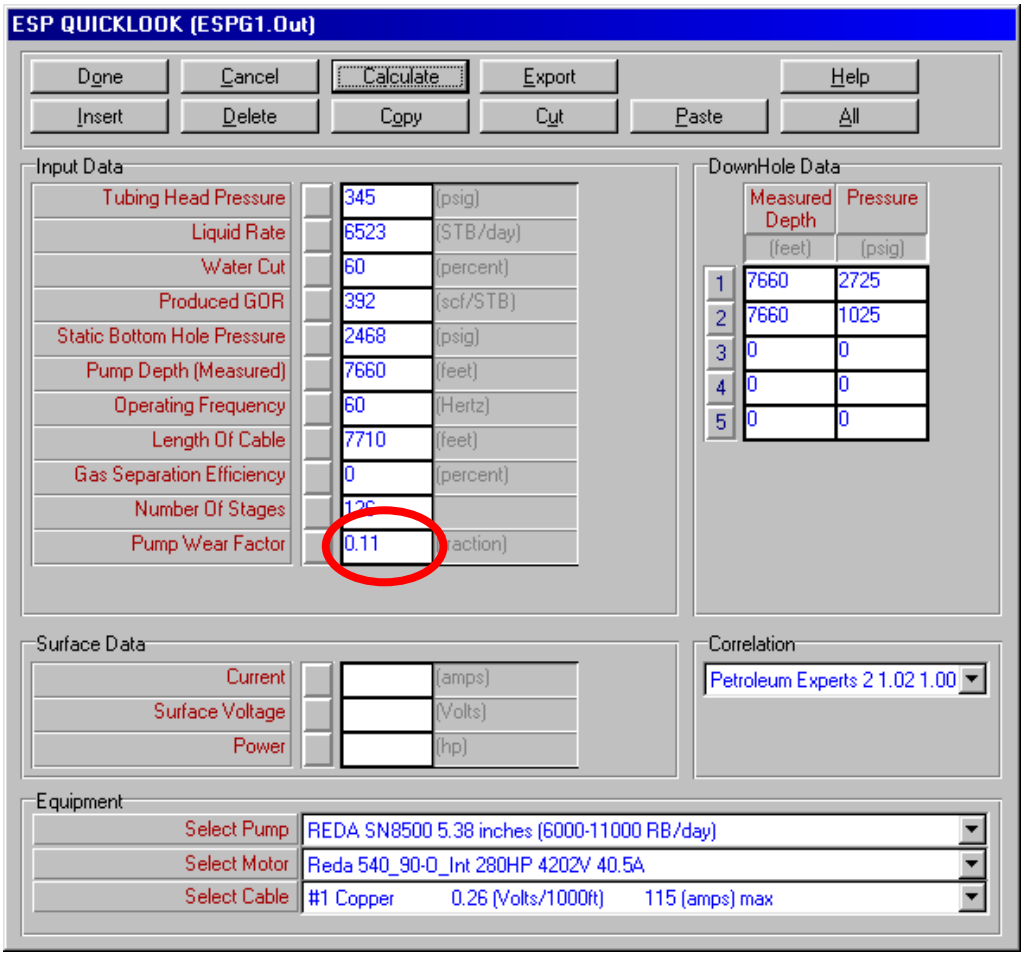


Figure 137: ESP QuickLook main screen

Then Calculate | Calculate and Plot. The following QuickLook plot is displayed:

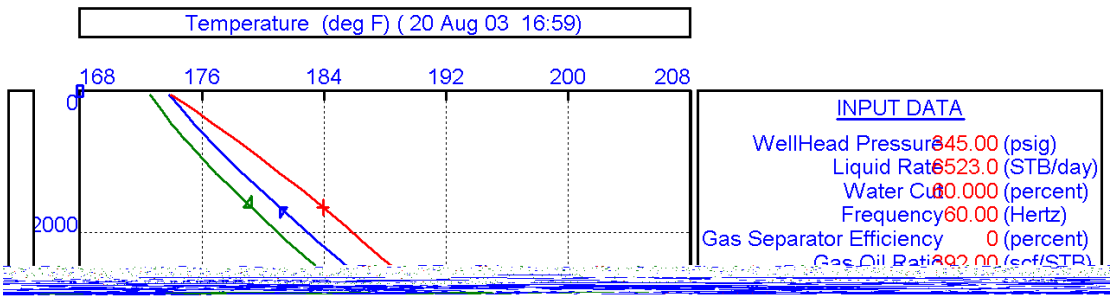


Figure 138: ESP QuickLook plot

The downward gradient is now matched.
All what we have to do now is to match the upward gradient to this. The upward gradient is calculated starting from the bottomhole pressure given by the IPR. So, it depends on the inflow.
In order to match the upward calculated gradient, let us go to the IPR section and decrease the PI to 6.3 STB/day/psi. Then, back in the QuickLook section, calculate and display again the QuickLook plot:

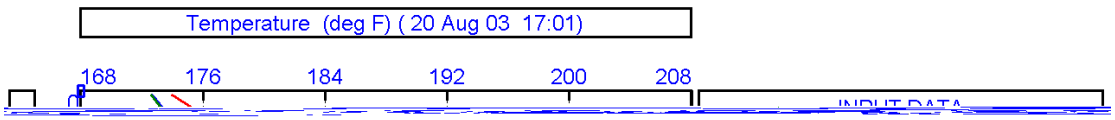


Figure 139: ESP QuickLook plot

This match is acceptable. This method can thus be used to trouble shoot and check the performance of operating wells, if we have down-hole and reliable flow measurements available.

Save this file as espg1.out.

3.3 MBAL Gas History Matching Example

This tutorial example is designed to provide a continuation of the step by step introduction to the **MBAL** program, following on from the **MBAL** Gas Reservoir Example. The emphasis here is on the steps required to match a production history using a material balance model to estimate the original gas in place within a dry gas reservoir.

The driving mechanisms within the reservoir will be identified, increasing understanding of the reservoir's potential production. Relative permeabilities for gas and water will be estimated by matching fractional water production to simulated water saturation and tested by performing a prediction calculation.

3.3.1 STEP 1 : Initialise MBAL

Start the **MBAL** program by running **MBAL**.EXE, which can be found in the PETEX directory (default C:\Program Files*Petroleum Experts*\IPM 4.0). See the **MBAL** manual for more details on how to start **MBAL**.

Check that the current version of **MBAL** has been loaded. Select **Help | About MBAL Package** to check the version number.

Select **File | Open** to open the file created from the **MBAL** Gas Reservoir Example in the Dexterity section - **GASRES.MBI**. Immediately save this as a new file (GASRES2.MBI) using **File | Save As**.

3.3.2 STEP 2 : Add Production History Data

Production history data is entered and an aquifer model is initialised in this section. Enter the production history shown below in Table 1 by selecting **Input | Tank Data** and selecting the **Production History** tab. This data is also contained in an EXCEL spreadsheet named GASRES2.XLS and the data (select cells A5:F25) may be copied and pasted into **MBAL** using a **right mouse click** to select **Copy** within EXCEL and then **Paste** in **MBAL**. Alternatively the standard shortcuts **Ctrl C** and **Ctrl V** may be used to copy and paste data.

After evaluating the possibility of the existence of an aquifer, the following data can be used as a starting point:

Model	Hurst-van Everdingen Modified
System	Radial Aquifer
Reservoir thickness	100 ft
Reservoir radius	5000 ft
Outer / Inner radius ratio	5
Encroachment angle	360 degree
Aquifer permeability	20 md

3.3.3 STEP 3 : Material Balance Introduction

A very brief introduction to the material balance method is included here.
The governing principal is mass conservation as the reservoir is produced. This may be restated as:

The volume of material removed by production at reservoir conditions is replaced by fluid/formation expansion and possibly aquifer inflow

The equation below represents this volume (material) balance at reservoir conditions (pressure and temperature):

$$F = N.Et + We$$

- **F** is the produced fluid volume at reservoir conditions. Good production history and ***PVT*** is required to estimate this quantity.
- **N** is the original oil/gas volume in place, which can be estimated by geological investigations.
- **Et** is the expansion of the reservoir fluid and water, and formation rock compaction following the depressurisation of the reservoir as it is produced. Good reservoir pressure history and ***PVT*** is required to estimate Et. Note that for oils, good ***PVT*** (Bo) above the bubble point is especially important, since the compressibility of undersaturated liquid oils is relatively small.
- **We** is the volume of aquifer water entering the initial reservoir volume.

In general, if good ***PVT*** and production history is available, **F** and **Et** are reasonably well known. Also, an initial estimate of **N** can usually be made. The question then is to refine correlations for **We** and the value of **N** to match the production data. The material balance equation above can be rearranged to perform non-linear regression on **N** and aquifer model parameters.

The quality of the ***PVT*** and production history data is vital to the material balance calculations. However for simplicity, this example uses an unmatched Black Oil ***PVT*** and a fictitious production history.

3.3.4 STEP 4 : Material Balance Matching

The production history data will be matched to a material balance model using judgment and non-linear regression. The drive mechanisms within the reservoir and the Original Gas In Place (OGIP) will be estimated.

The History Matching starts considering no aquifer is present. So, the Tank Input data screen, we choose No Aquifer.
It is suggested that the **MBAL** window is made **full screen** to aid viewing. Select **History Matching | All**. Three screens appear graphically illustrating the fit of the material balance model to the production data and reservoir pressure.

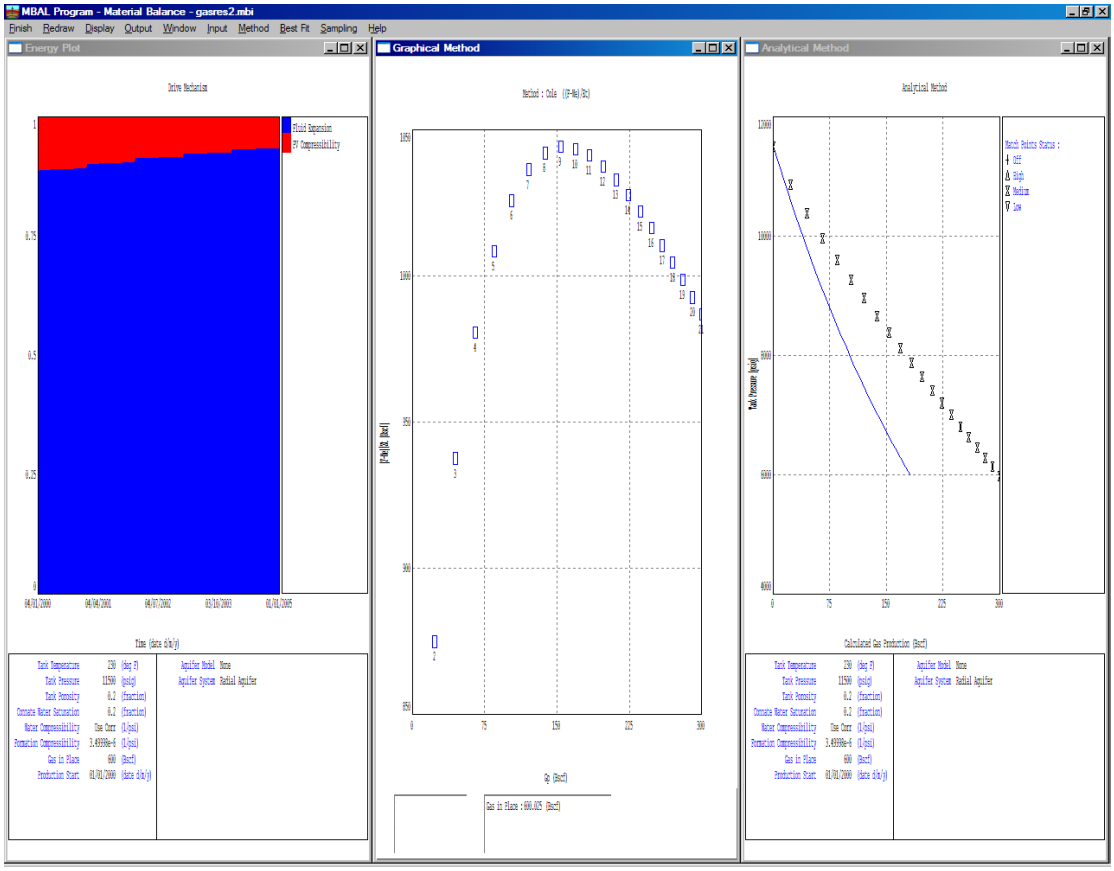

MBAL Program - Material Balance - gasres2.mbi
Finish Redraw Display Output Window Input Method Best Fit Sampling Help
Energy Plot
Graphical Method
Analytical Method

Figure 140: History matching plots

The material balance model is defined by the correlations and parameters entered in the **Input | Tank Data** screens. All of these may be altered at any time to improve the fit, but only the OGIP and the aquifer model parameters may be modified by non-linear regression. This reflects the observation that these are generally the least well known variables.

It is very important that a systematic methodology is followed, based on an understanding of the material balance model, rather than a series of regressions. It should be understood that the regression solutions are not necessarily unique and work better if their values prior to regression are not too far from a solution. Therefore the interpretation of the graphical representations of the material balance model must be used to refine the model before regression should be used.

An aquifer model is present, but is providing no water (We = 0). Highlight the **Graphical Method** window by clicking the left mouse button within its title bar, and select **Method | Cole ((F-We)/Et)**. Recall the material balance equation (F-We)/Et = N (F/Et = N, when We = 0). If the material balance model was well fitted to the production data then the Cole plot should be a horizontal line with a value equal to N (OGIP).

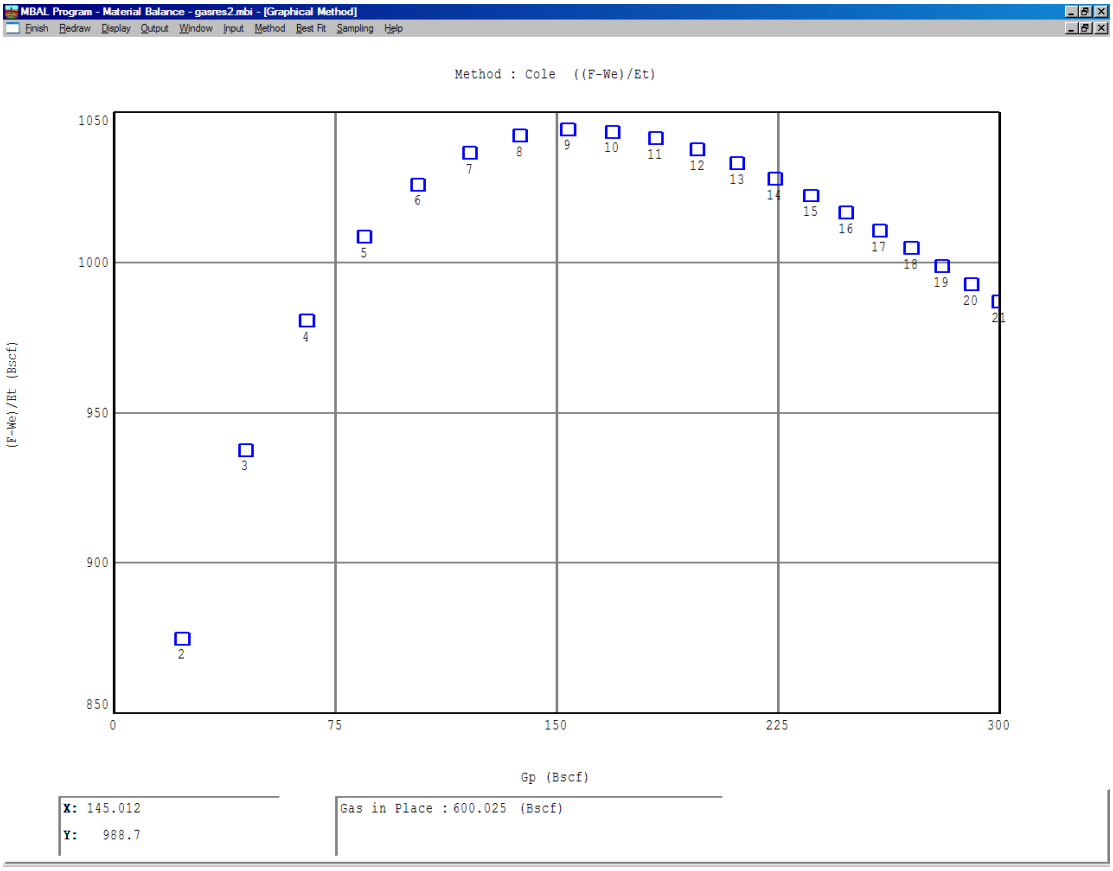


Figure 141: Graphical Method showing Cole Plot

The initial rise indicates an increasing apparent value for N. The expansion (Et) of the reservoir fluids/formation alone is not sufficient to maintain the reservoir pressure. There is more energy in the reservoir than the current material balance calculation is predicting. These equivalent statements imply the reservoir pressure is being maintained by another mechanism, the likely candidate is an aquifer.

An aquifer model can be added to the model, based on the initial estimates given in the introduction:

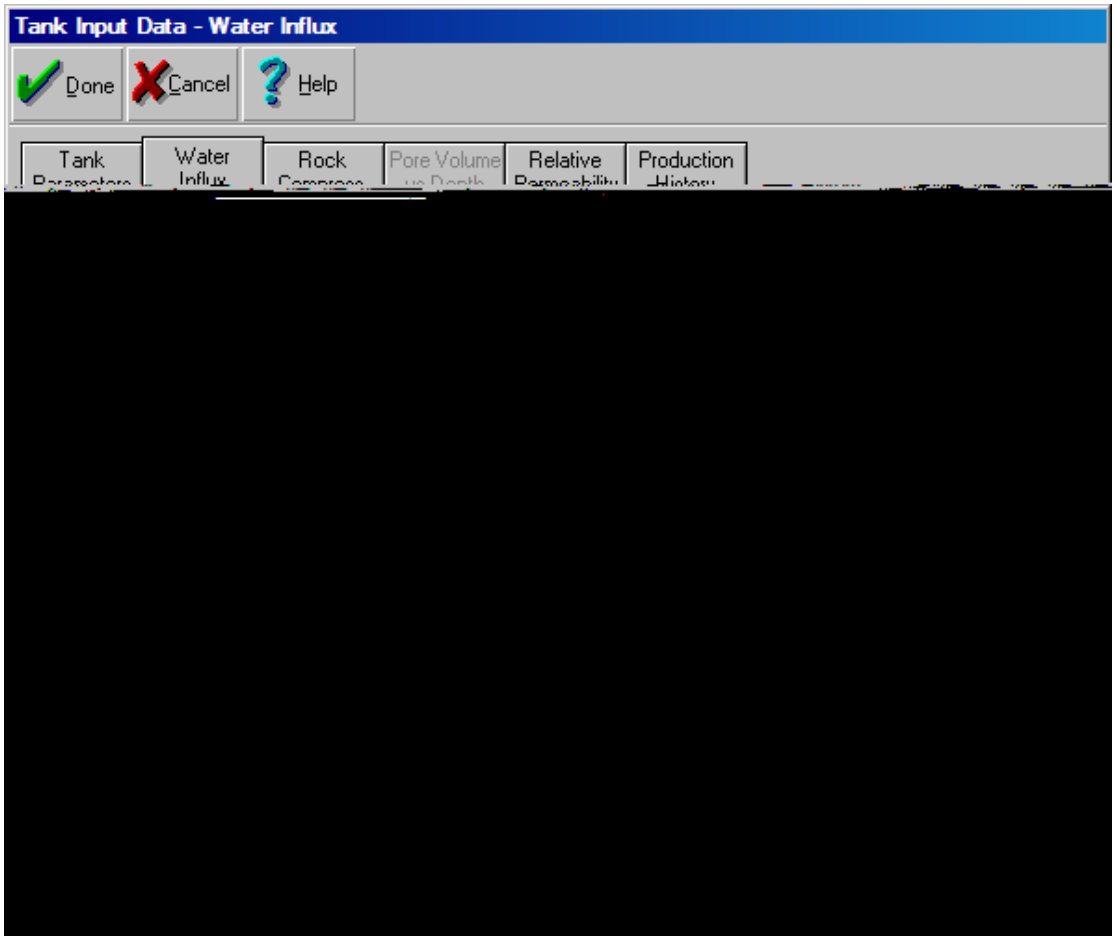


Figure 142: Initializing an aquifer model

Also note that the rise of the Cole curve does not continue, but levels out and then starts to fall at later times. This can be interpreted as the aquifer inflow slowing at around data point 5 and stopping near data point 10. This means that around this time the outer boundary of the aquifer has been 'felt'.

At early times, the well will not 'see' the aquifer. Therefore the early values on the Cole curve indicate minimum values for N. Select **Display | Scales** and set the Y-axis bottom value to 600 Bscf and select **Done**. An extrapolation of the Cole curve towards the Y axis is difficult, emphasising the importance of early data recording. However, an extrapolation to the Y-axis would suggest a value for N larger than 600 Bscf, perhaps nearer 750 Bscf.

Next, the value for N shall be updated to 750 Bscf and the aquifer model will be started. Highlight the Analytical Method window and select Regression from the menu toolbar.

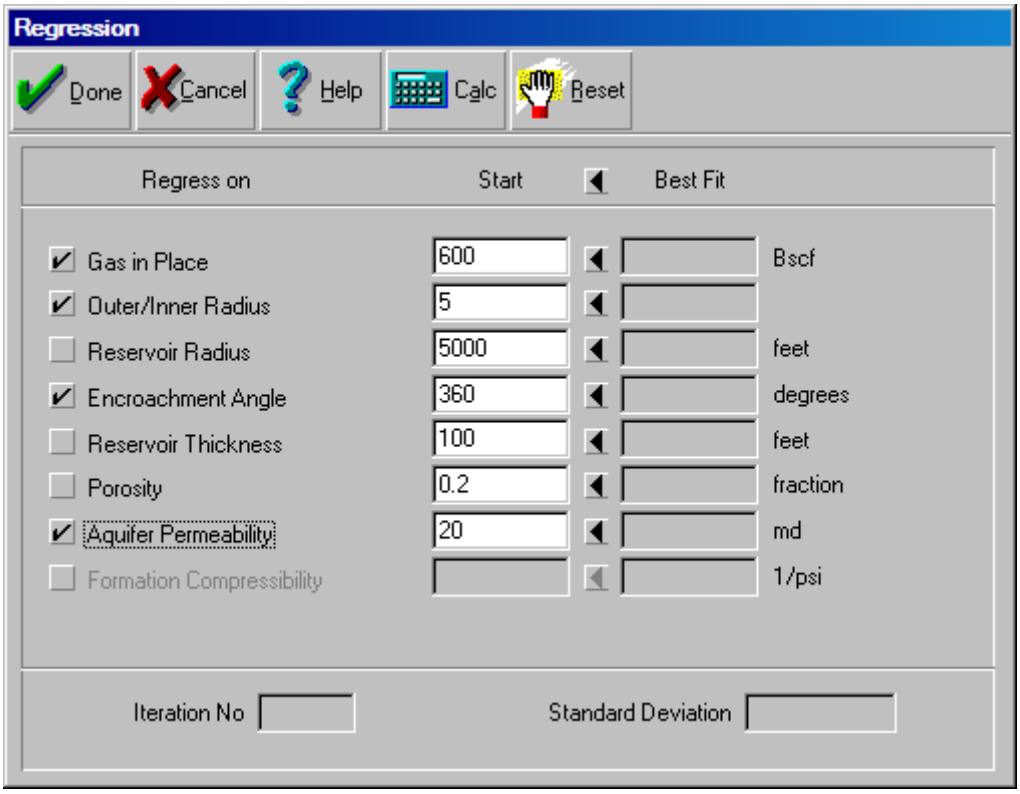


Figure 143: Modified OGIP and Outer/Inner Radius

Set the Gas in Place to 750 Bscf and the Outer/Inner Radius to 5 and select **Done** to display the recalculated material balance.

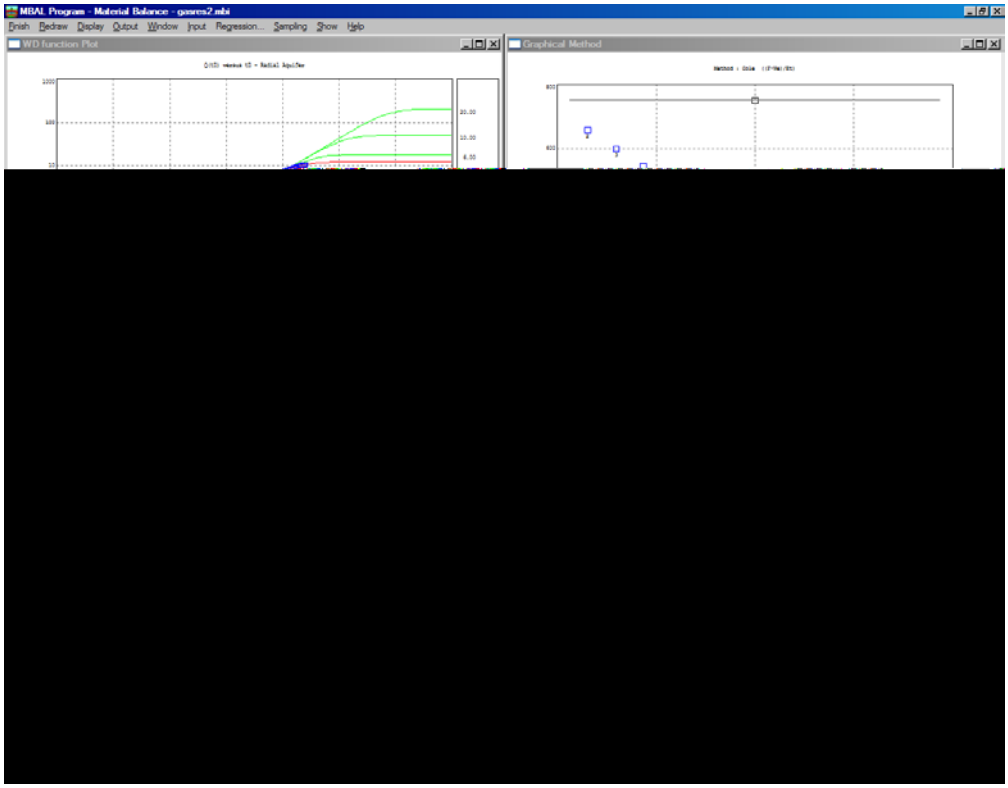


Figure 144: History matching plots

From the Graphical Method screen (top right of **Figure 144**) it is clear that the aquifer that has been added is too strong, it is providing too much energy to the system. The extrapolation of the Cole curve to the Y-axis suggests a possibly reduced OGIP (N).

Look at the WD function Plot screen (top left of **Figure 144**). This shows a dimensionless time (tD) and dimensionless aquifer inflow volume (Q). The 'elbow' of this curve occurs at the point where the aquifer cannot supply additional water; the boundary of the aquifer has been 'felt'. Recall that the initial Cole curve suggested this occurred between data points 5 and 10.

Move the cursor within the WD function Plot screen and double click left. This alters the Outer/Inner Radius parameter of the aquifer model, altering the displays in the other Method screens. In particular, notice that the Analytical Method gas production/pressure curve moves. By double left clicking in the WD function plot screen, try to select an aquifer Outer/Inner Radius parameter that shows a reasonable fit to the production displayed in the Analytical Method screen. An Outer/Inner Radius of about 2.1 works quite well, but the 'elbow' on the WD function Plot is not between data points 5 and 10.

Highlight the Analytical Method window and select Regression from the toolbar. Set the Outer/Inner Radius to 2.1 in the start (left) column and select Done to view the results.

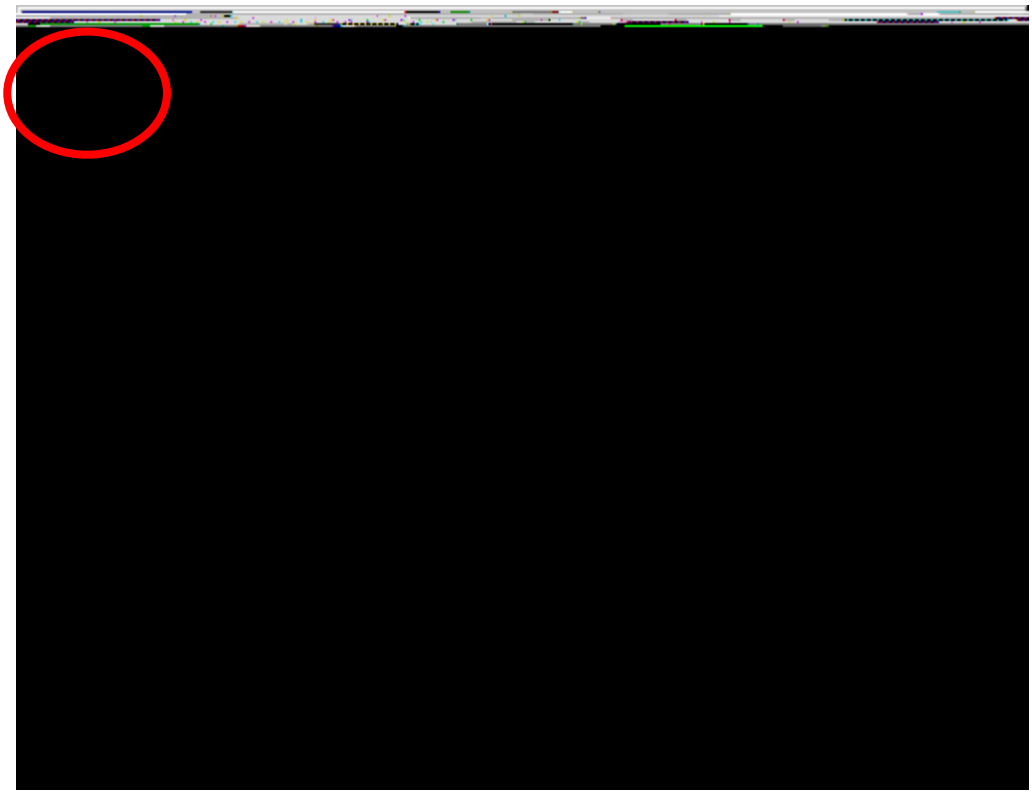


Figure 145: Modified Outer/Inner Radius

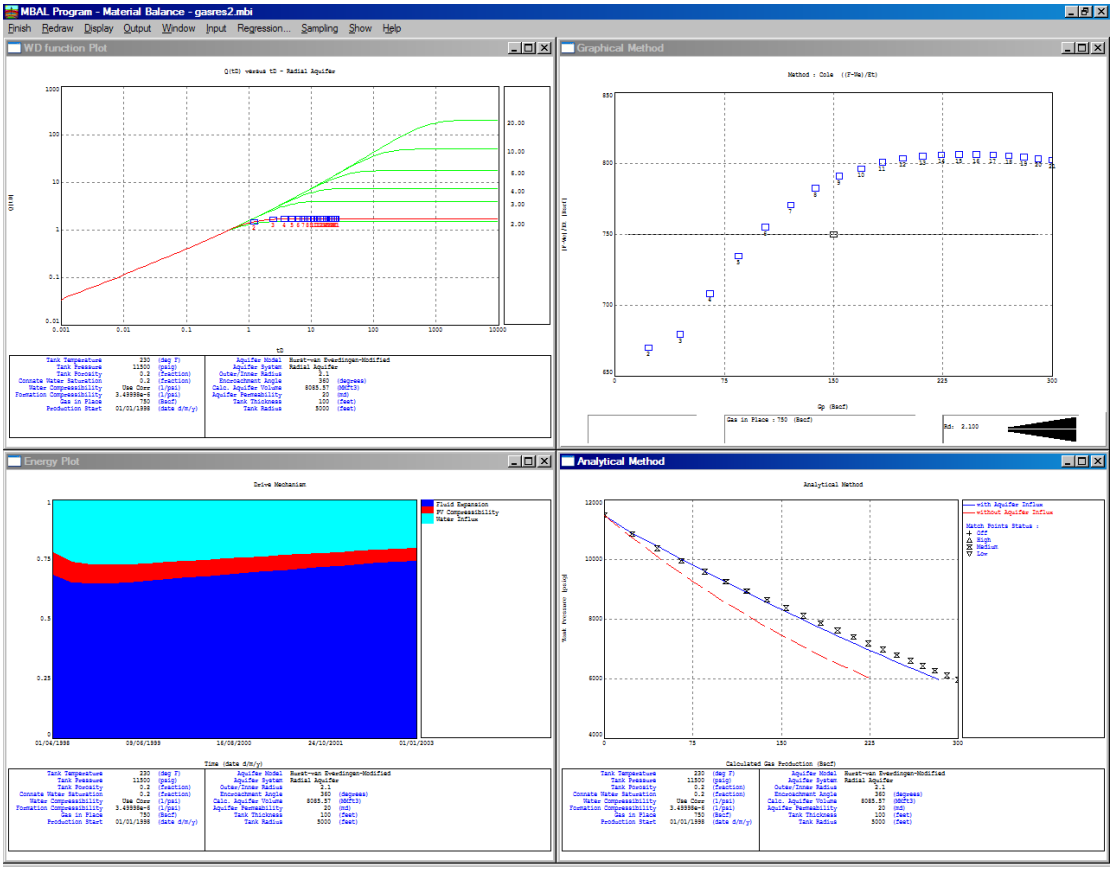

MBAL Program - Material Balance - gasres2.mbi
Finish Redraw Display Output Window Input Regression... Sampling Show Help
WD function Plot
Graphical Method
Energy Plot
Analytical Method

Figure 146: History matching plots

The data points at very early times may only be reflecting responses from regions in the vicinity of the well and don't necessarily show responses of the entire reservoir, therefore the material balance would not be expected to show the complete OGIP until the pressure signal from the producing well has had time to permeate the entire reservoir. It is possible that the Graphical Method screen is showing this effect at early times. The signal time to permeate the reservoir can be estimated from the diffusivity and reservoir dimensions. The diffusivity, $D=k/\varphi\mu c$ (ft2s-1) relates the radial pressure response at a distance r and time t from the well source by the equation $P \propto \exp(-r2/4Dt)$.

For this example the first data point shown (point 2) is one year after the start of production and can probably be expected to reflect the whole reservoir's response, suggesting that the aquifer model still requires some fine tuning. Note also that the 'elbow' of the WD Function Plot is not reflecting correctly the time at which the aquifer energy is exhausted.
However, recognising the points noted above, the material balance model is now not too far from being consistent with the production data and non-linear regression may be used to refine the model parameters.

Highlight the Analytical Method window and click on Regression. Check the Gas in Place, Outer/Inner Radius, Encroachment Angle and Aquifer Permeability boxes to regress on.

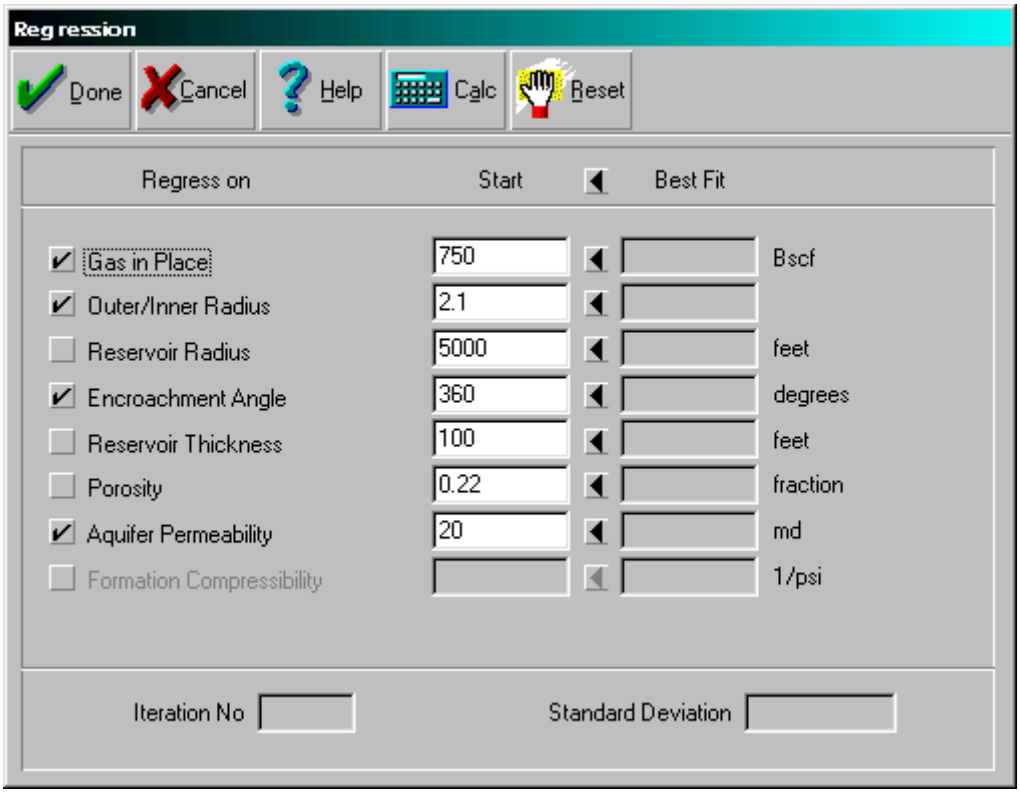


Figure 147: Select variables to regress on

Select Calc to start the regression. When it finishes, copy the 'Best Fit' values to the 'Start' values by clicking the left pointing arrows (**Figure 147**). You may select the left pointing arrow between the 'Start' and 'Best Fit' headings to copy all of the regressed values. Select **Done** to view the changes.

Do not regress on combinations of parameters that are simply multiplied by each other in the aquifer model. For example, the Hurst-van Everdingen aquifer constant contains the product of porosity, reservoir thickness, encroachment angle and the square of the original reservoir radius. If a regression is performed on pairs of these parameters, then the regression will not converge easily, particularly if the initial values are not close to a solution.

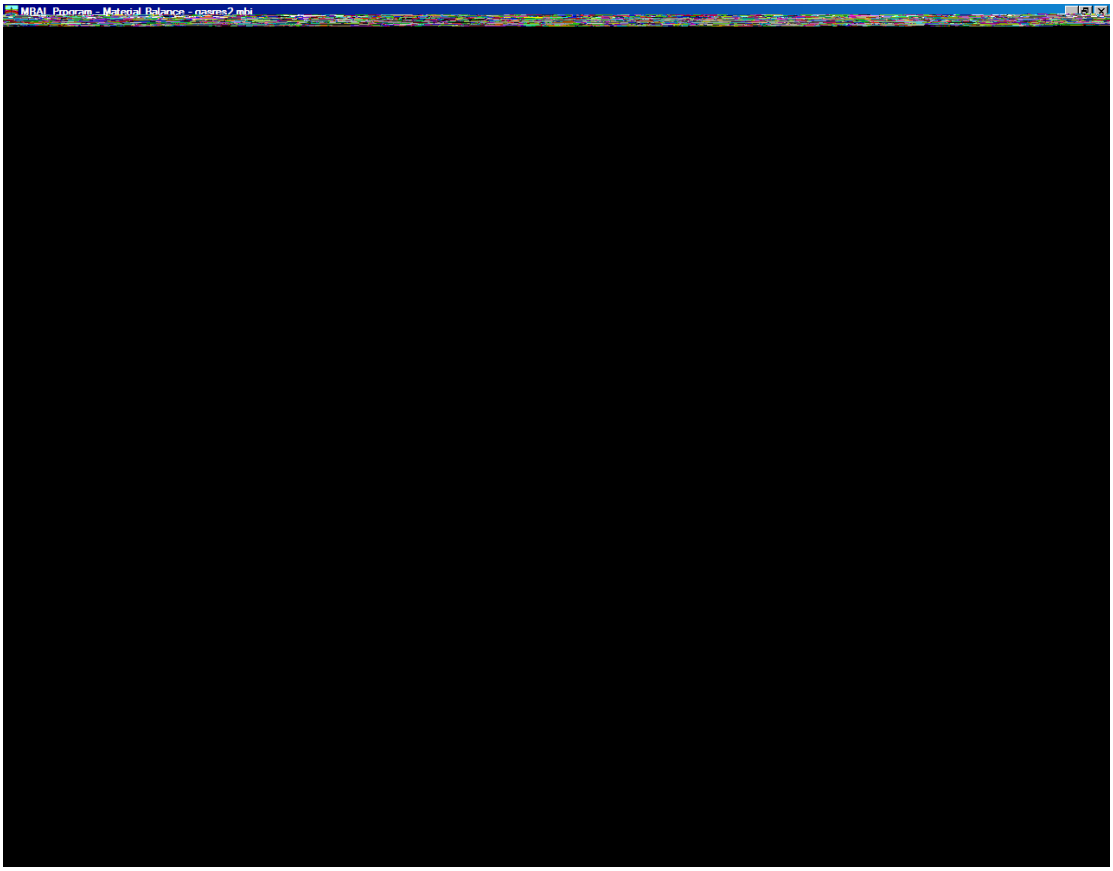


Figure 148: History matching plots

The match now is very good (**Figure 148**), the aquifer model and OGIP are consistent with the production history. Note however, that although the actual values calculated for the aquifer model taken together describe the aquifer well, the individual parameter values do not in themselves necessarily correspond to reality. These parameters are not a unique set that characterise the aquifer.

Select **Finish | File | Save**.

3.3.5 STEP 5 : Relative Permeability Matching

In this section, the effective relative permeability of water will be obtained by matching the fractional water flow obtained from the production history to the fluid saturations calculated by a material balance simulation.

Relative permeabilities were not used during the material balance matching and are not used during the simulation calculation, since the produced water and gas are input as part of the production history. The simulation is merely providing the water saturation within the tank model, resulting from a material balance simulation.

Select **History Matching | Run Simulation | Calc** to run a material balance simulation of the production history. Select **OK** when the calculation has completed.

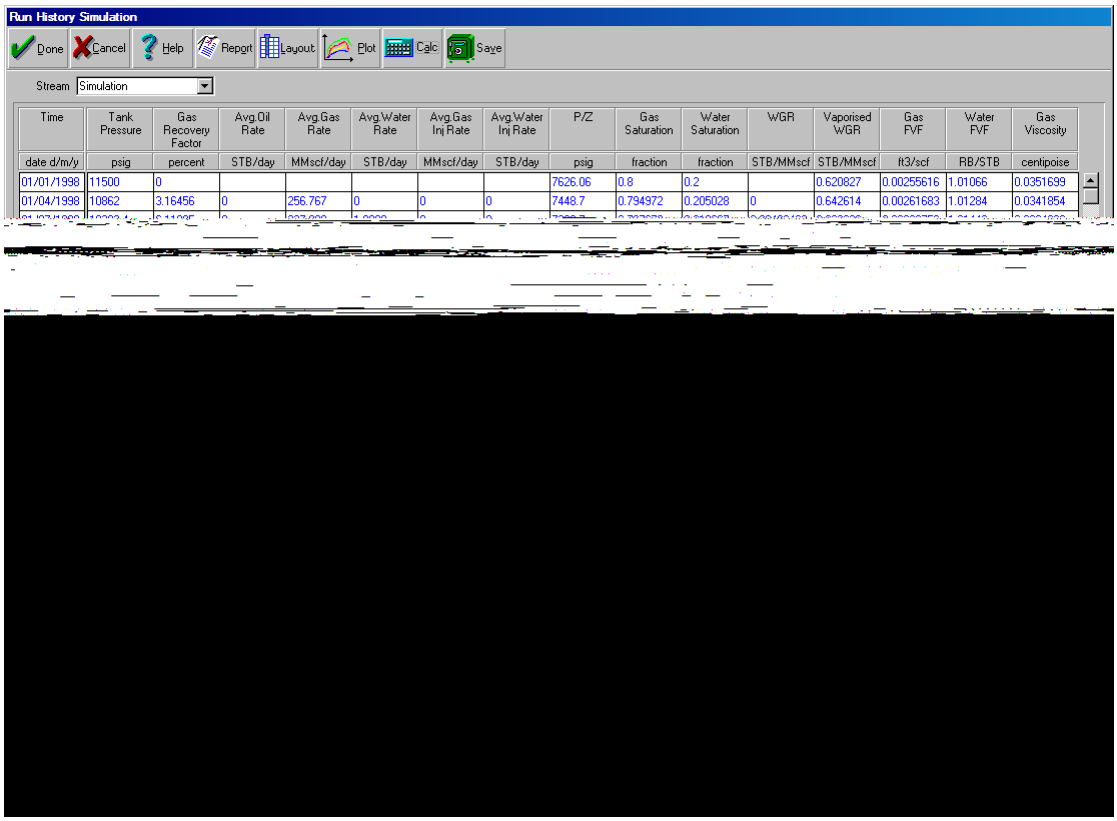


Figure 149: Simulation results

Return to the main **MBAL** display by clicking **Done**. Next, select **History Matching | Fw Matching** to display the matching screen.

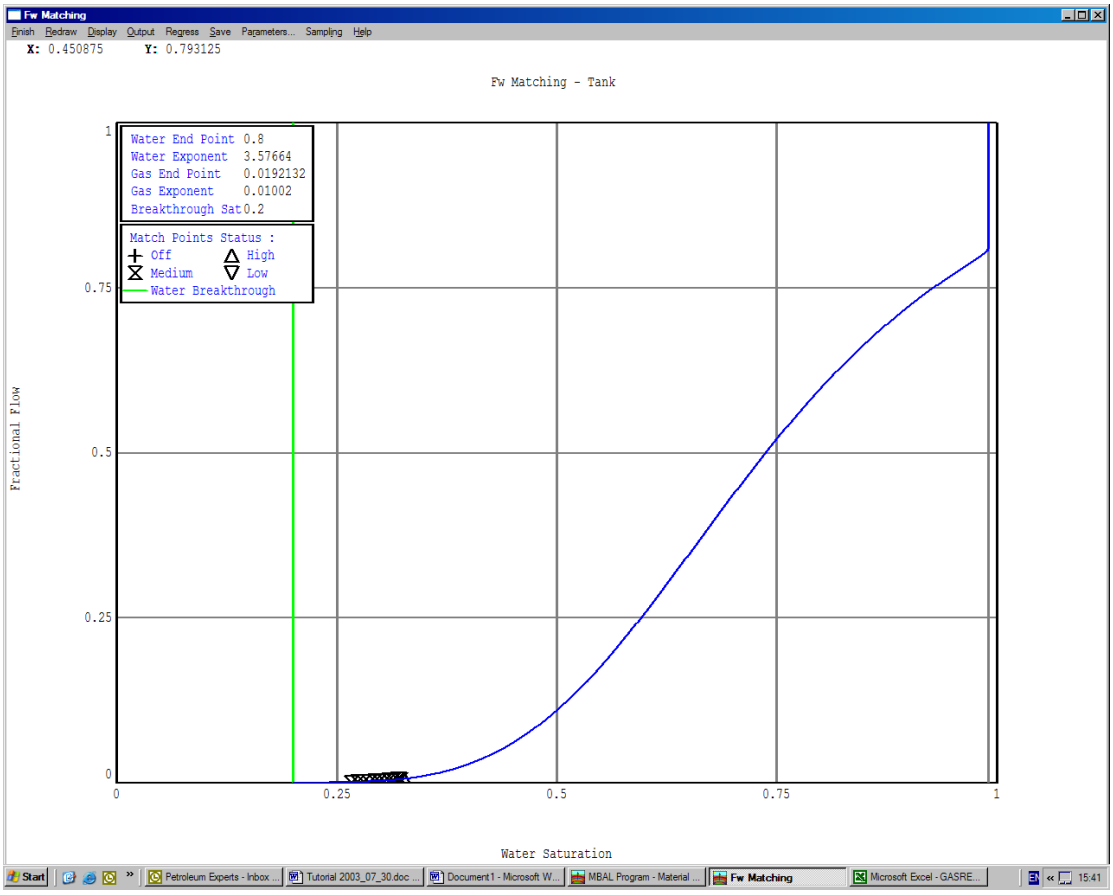


Figure 150: Fw matching screen

Within this screen, the fractional water flow is plotted as a function of water saturation. The water breakthrough point can be set by a double left click at an appropriate saturation (a dashed green line is shown at the new breakthrough saturation). Note that a breakthrough point below the connate water saturation (indicated by a grey line) is not possible. Additionally parameter values can be entered by selecting **Parameters.** Leave the water breakthrough saturation at the connate water saturation (0.2).

A region of the display can be enlarged by holding down the left mouse button and dragging it to select the desired region. The original display can be redrawn by selecting **Redraw**. Production history data points may be selected by holding down the right mouse button and dragging it to select the desired points. The weighting of the selected points may be altered, or excluded from use in the regression.

Select **Regress**, then **Parameters** to display the matched parameters (**Figure 151**). Select **Finish | Yes** to save the matched Corey coefficients.

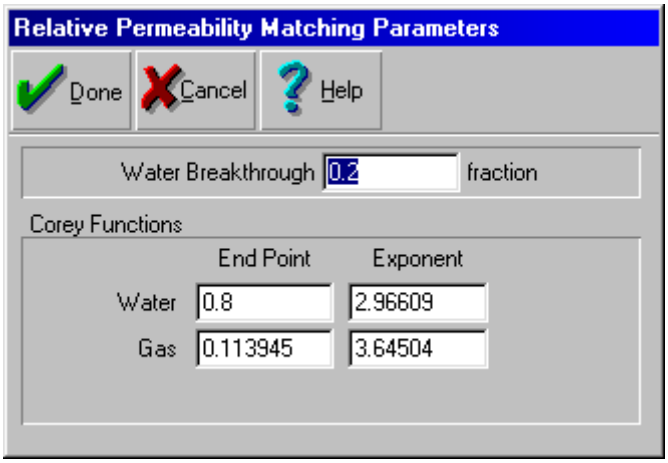


Figure 151: Matched Fw Parameters

It is now desirable to perform a material balance predition to check that the fraction flow of water is sufficiently well characterised by the matched relative permeability model. A prediction calculation in its simplest form requires a history of oil or gas production rates (copied from the simulation calculation), from which everything else is calculated. Of particular interest will be the predicted WGR (Water Gas Ratio).

Select **History Matching | Run Simulation | Report** and check report to Clipboard with the 'Tab delimited' format.

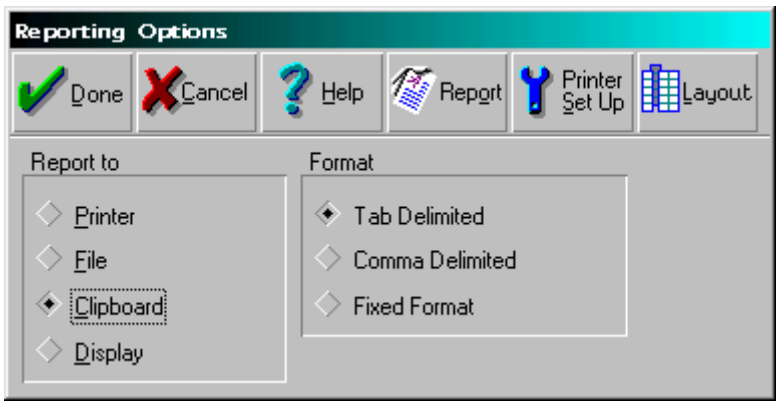


Figure 152: Reporting data

Select **Layout | Hide All** and then highlight **Time** and **Average Gas Rate.**

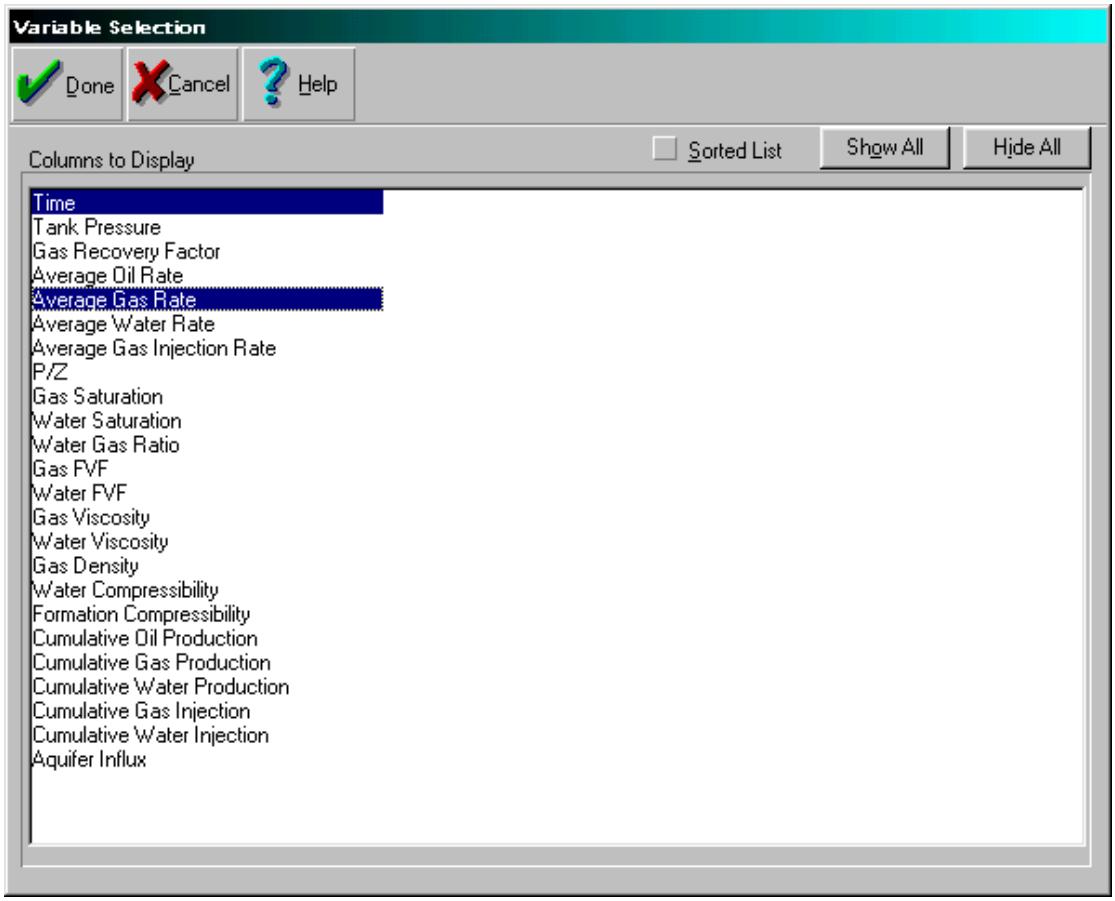


Figure 153: Selecting items to report

Select **Done | Report** to save the results to the clipboard. Select **Done** to return to the main **MBAL** window and open EXCEL and paste the the contents of the clipboard into it. The simulation average gas rates are recorded at the end of each time step.

From within **MBAL** select **Production Prediction | Prediction Setup** and set the prediction method as shown in **Figure 154** and select **Done**. Ensure that **Use Relative Permeabilities** is checked and the Prediction End is set to **End of Production History**.

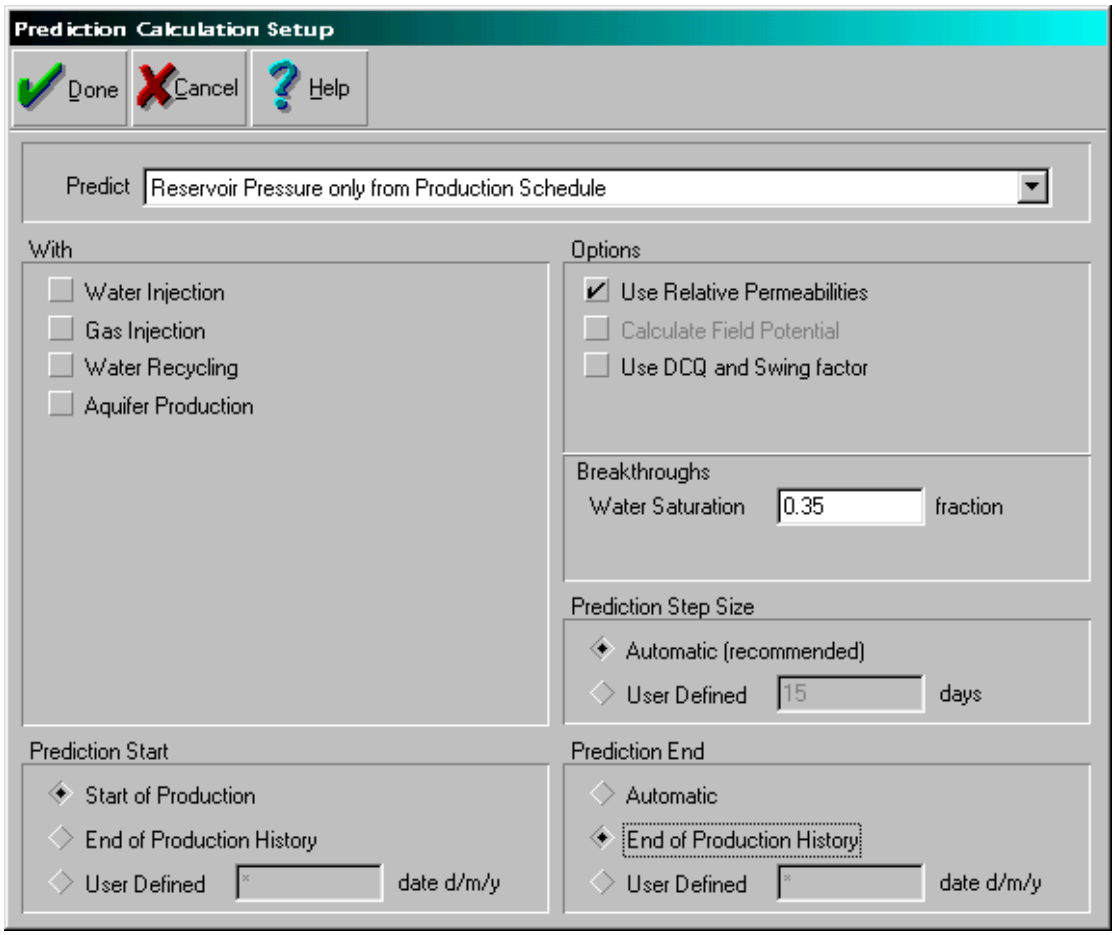


Figure 154: Prediction Setup Screen

Select **Production Prediction | Production and Constraints** and copy the production gas history (by selecting Copy) into the production constraint screen (**Figure 155**) and select **Done**.

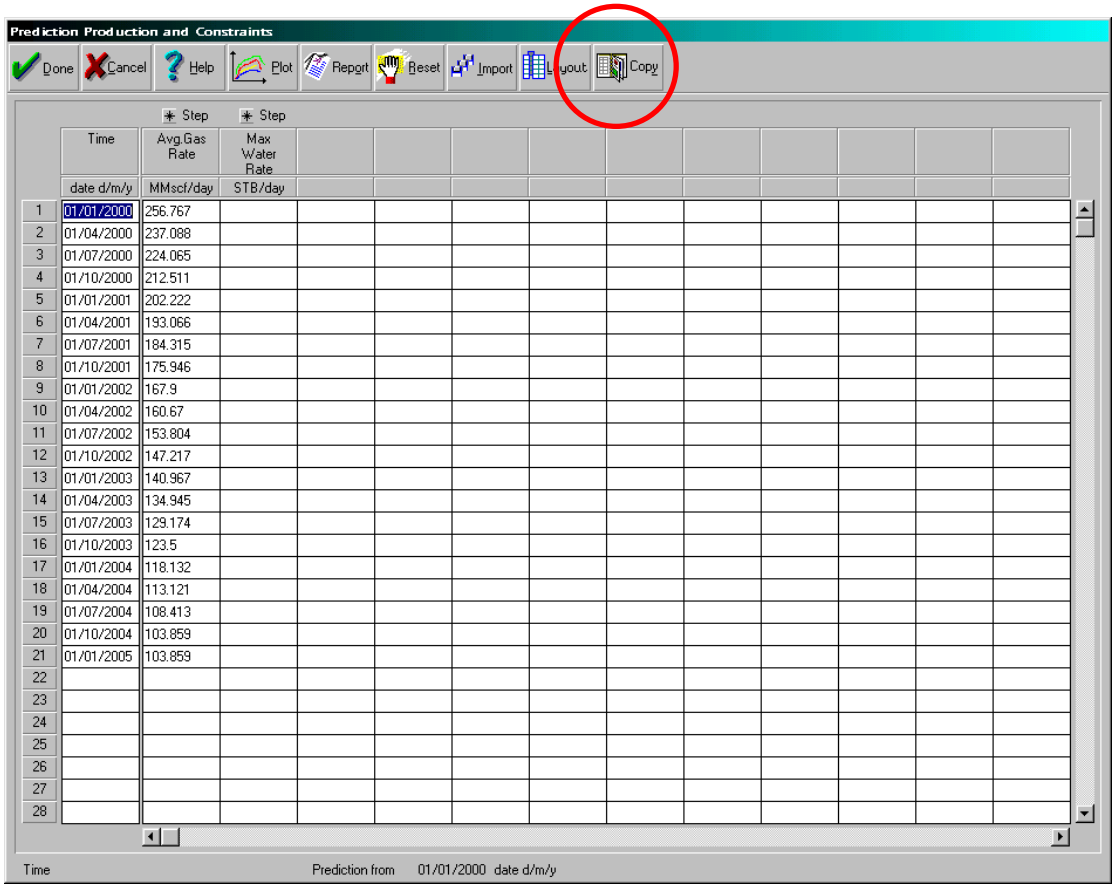


Figure 155: Production Prediction Screen

Select **Production Prediction | Reporting Schedule.** Here, we need to specify how frequent do we need **MBAL** to report the results. We can set to automatic. Hence, click on **Done** to accept automatic reporting. Then, hit on **Prediction | Run Prediction | Calc** and **OK | Plot** when the calculation has completed. Select **Variables** and highlight streams **Simulation** and **Prediction**, and plot **Pressure**, then select **Done** to view the plot.

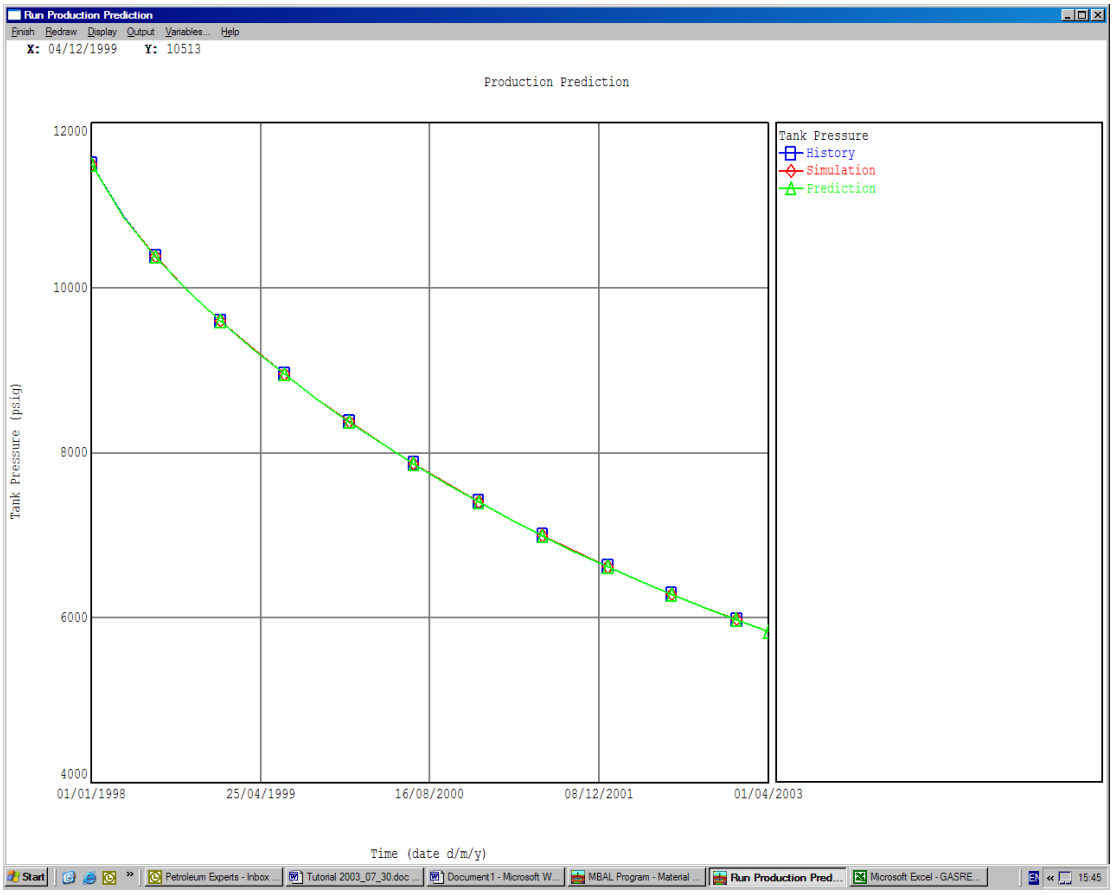


Figure 156: Comparing simulation and prediction results

For this example the prediction is very good and some confidence in future predictions can be expected. If the prediction does not model the fractional productions well, then the fractional flow can be rematched using different data point weightings or Corey parameters altered by hand.

Select **Finish | Done | File | Save** to complete this tutorial example.

3.4 MBAL Oil History Matching Example

This example presumes that the user is familiar with setting up single tank models in **MBAL**.

In this exercise the objectives are:

- Quality-check the production data that is available. This quality check is based on what is possible physically.
- Based on the checked data build **MBAL** model and identify various drive mechanisms and fine tune Oil in place (OIP) estimates using History matching techniques.
- Quality-check the fine tuned **MBAL** model selected after history match using techniques available in **MBAL** software.

Methodology:
The oil reservoir model will be built step by step. At each step if any laboratory or field data is available, its quality will be checked and then it will be used in the model.

The available data is described in the following sections.

3.4.1 PVT Data

(@ 250 deg F)

- Bubble point (P_b) = 2200 psig
- Solution GOR = 500 SCF/STB
- FVF@ P_b = 1.32 RB/STB
- Oil Visc.@ P_b = 0.4 cP
- Oil gravity = 39 API
- Gas grav. = 0.798
- Water Salinity = 100,000 PPM

3.4.1.1Production data

This data is contained in an Excel file OILRES1.XLS. Later in this chapter a description on how to transfer the data from Excel into **MBAL** will be provided.

3.4.2 Setting up the Basic Model

Note: If you comfortable with setting up basic **MBAL** single tank models, you can skip this section and go to the next section. The basic tank model that this section is used to set up is under the file name “res1.mbi”.

- Start **MBAL** and select the menu option **File | New**.
- On the menu bar go to **Tools** and click on **Material Balance**.
- On the menu bar go to **Options** and following screen appears. Fill the screen with the following details:

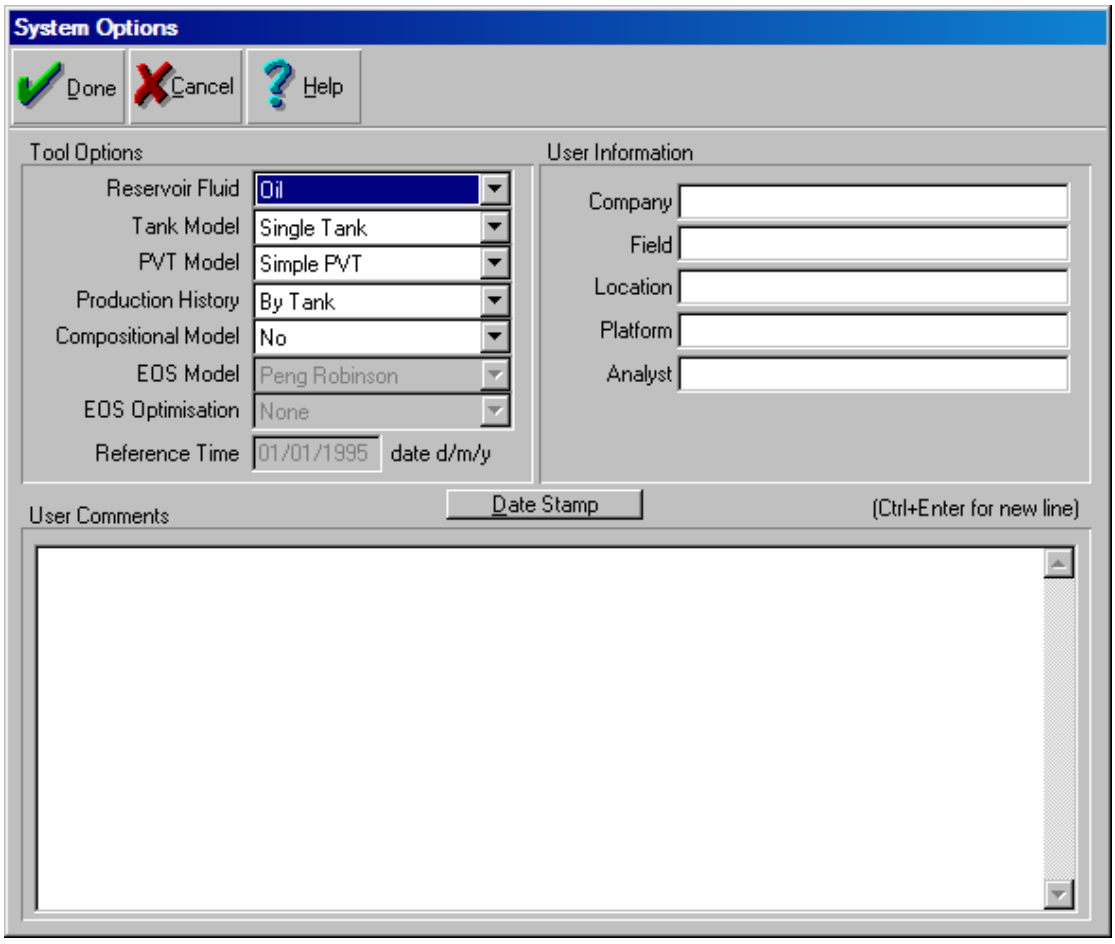


Figure 157: Setting the option

In this screen, you have defined oil as the main fluid, selected a simple tank model and will enter the production history by tank. You also do not want to do compositional tracking for this reservoir.

Then again on the menu bar go to **PVT | Fluid Properties** and supply the following data:

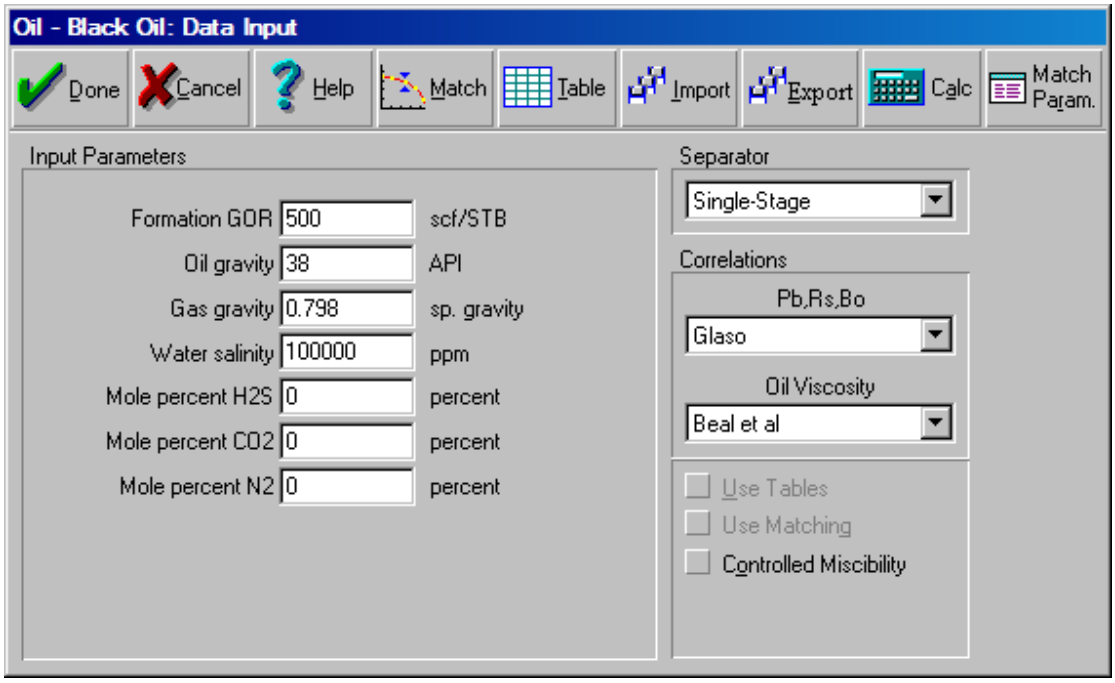


Figure 158: **PVT** input

In this section we have specified the Black oil properties of the oil as given in the ***PVT*** data available section. We also have specified water salinity and indicated that the produced gas has no CO2, H2S or N2 in it.

In the previous screen we also have indicated that we want the **PVT** behaviour to be predicted by Glaso and Beggs et al correlations. Since we do have laboratory measured data for this fluid at bubble point conditions as given in available **PVT** data section, we will match the lab data to the correlations that we are selecting. In the **PVT** Input dialog, press the **Match** button and the following screen appears and we can enter measured data at bubble point as indicated in the following screen:

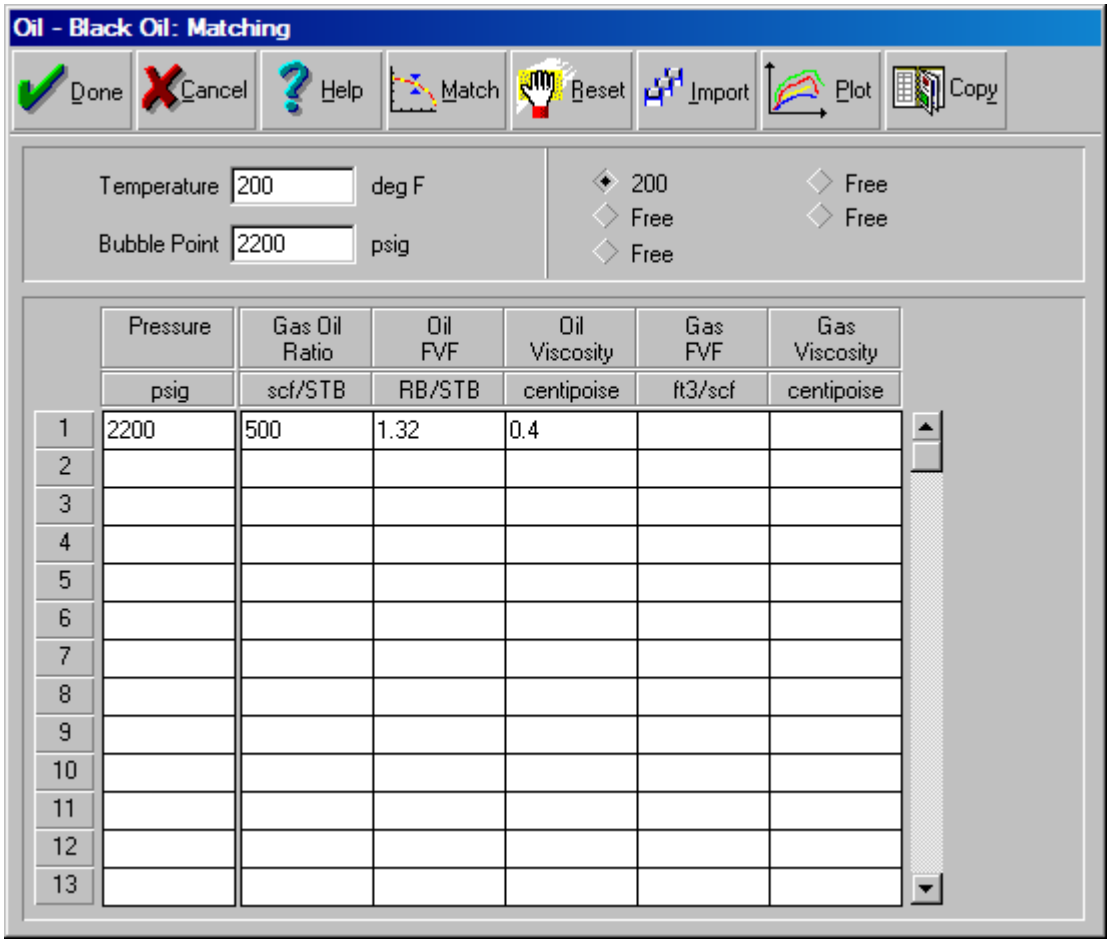


Figure 159: Entering **PVT** match data

After we have entered the data, if we click on **Match | Calc** this will start the matching process. Before you hit Calc, ensure that the Match all option as shown in the screen below is ticked. This will make the program match the lab data to all the correlations available in **MBAL**.

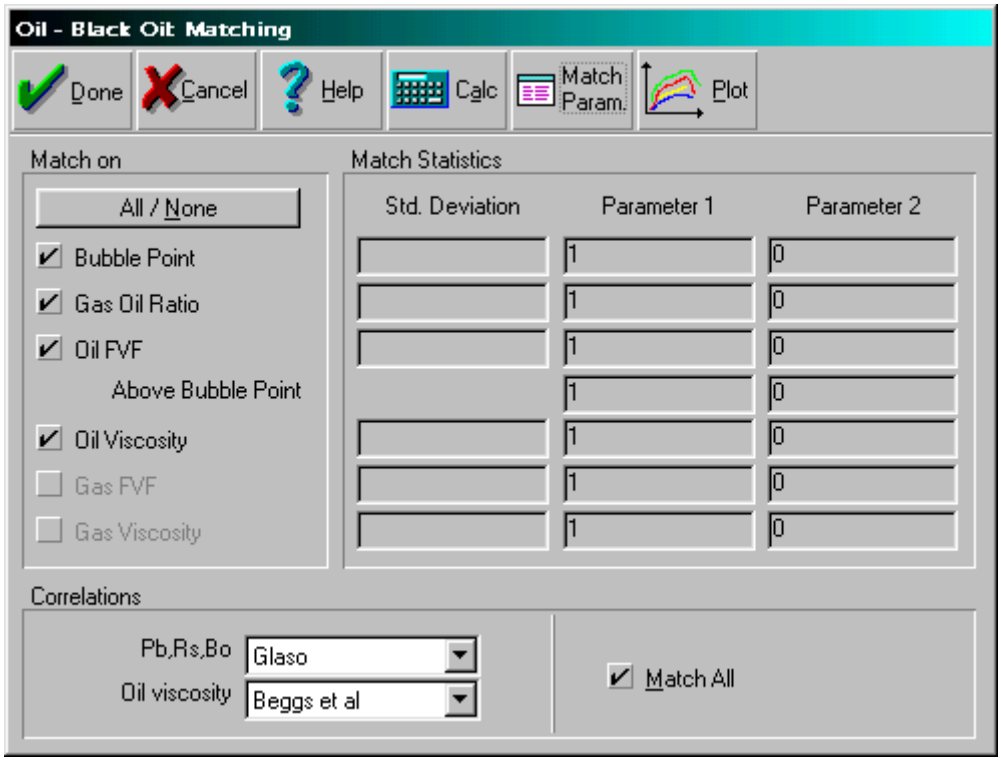


Figure 160: **PVT** matching

Once this is done, click the **Match Param** button to look at parameters of each of the correlations and the standard deviation, to see which of them does the best job. In this case we select Glaso for bubble point, GOR and FVF calculations; and Beggs for viscosity calculation.

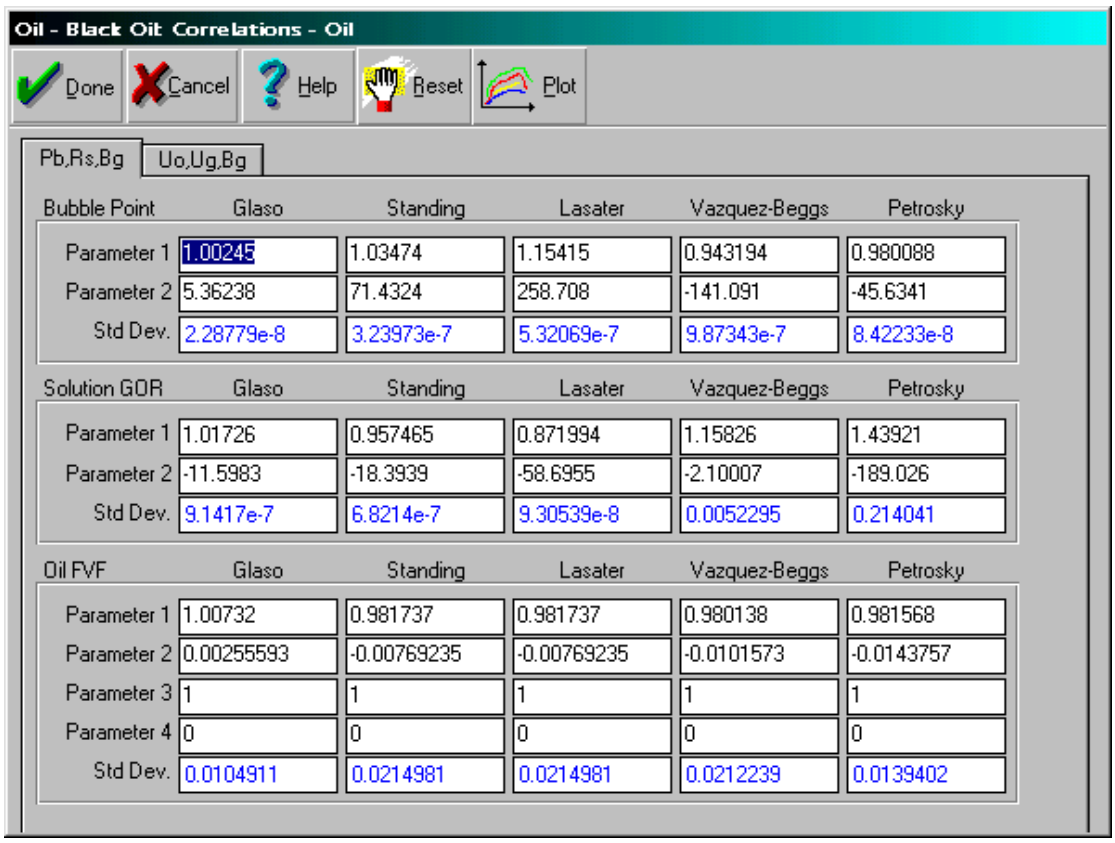


Figure 161: Matched parameters

At this stage you have finished specifying the **PVT** properties of the fluid of your tank. Now the next step is building your tank model. In the main menu bar go to **Input | Tank Data**, and supply the following information. This is the basic information about the reservoir that you must have.

Tank type	Oil
Tank name	Tank01
Temperature	250 degree F
Initial pressure	4000 psig
Porosity	0.23
Connate water saturation	0.25
Water compressibility	Use Corr
Initial gas cap	0
Original oil in place	206 MMSTB
Start of production	01/01/1998

Figure 162: Tank input screen – tank parameters

In this screen we have said that we have a reservoir which has **oil** as its primary fluid, it is at a temperature of 250 deg F, the initial pressure of this reservoir was 4000 psig. The average porosity within the reservoir is 23%. The connate water saturation is 25%. Note that the initial gas cap field is not available to be edited. This is because, in **PVT** section we specified that at 250 F, the bubble point was 2200 psig and at 4000 psig the reservoir will be undersaturated and will have no gas cap. The program on the basis of the tank temperature, pressure and the **PVT** section will determine whether the reservoir is undersaturated or not. In case it is not you will also require an initial estimate of the gas cap.

You also will be required to enter an initial estimate of Oil in Place, obtained from geological surveys for example. The screen also requires entering a start production date for this reservoir.

Next information to be supplied is the aquifer support to the field. As there are yet no evidence to suggest the presence of an aquifer, this will be left to “None” for the time being.

The next information about the tank that we will have to enter is the rock properties. We can enter rock compressibility by hand, we can use the correlations to evaluate rock compressibility for us or we can enter compressibility as a function of pressure in table form, if we have the data. In this example we select to use correlations.

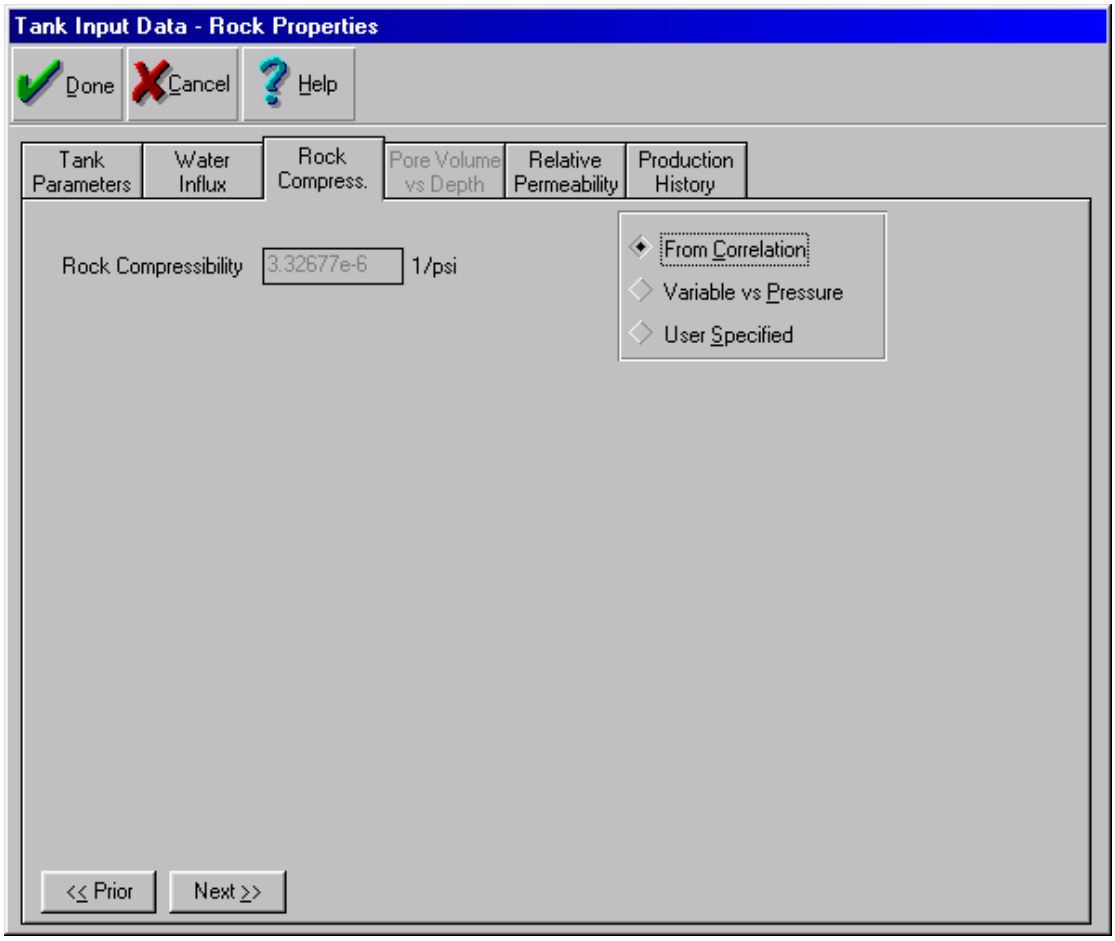


Figure 163: Tank input screen – Rock compressibility

The next data you have to enter is the relative permeability data. The relative permeability data is used in prediction calculations only. It is used to find WC and producing GOR, which are basically water fractional flow and gas fractional flow and depend on the water and gas saturation in the tank. If we have an initial gas cap and we are producing from it, we should use the total reservoir volume including that of gas cap to find saturation. If this is the case it should be selected in the screen of Tank Parameters. The relative permeability data can be entered as a table or as a Corey function. If you click on the **Rel Perm from** combo box, both these options are **REVEAL**ed. In this case we enter the Corey functions.

Phase	Residual Saturation (fraction)	End Point (fraction)	Exponent
Water	0.25	0.7	1.5
Oil	0.15	0.8	1.3
Gas	0.02	0.9	1

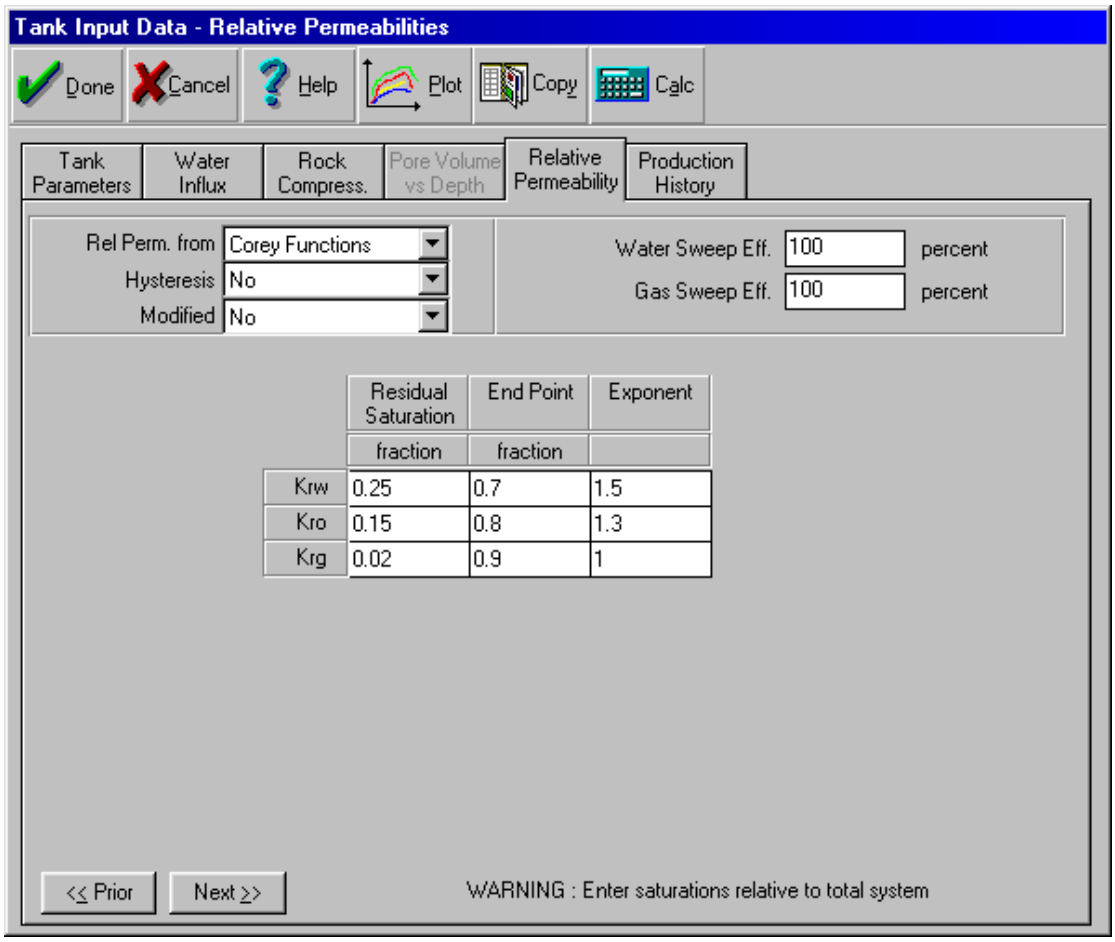
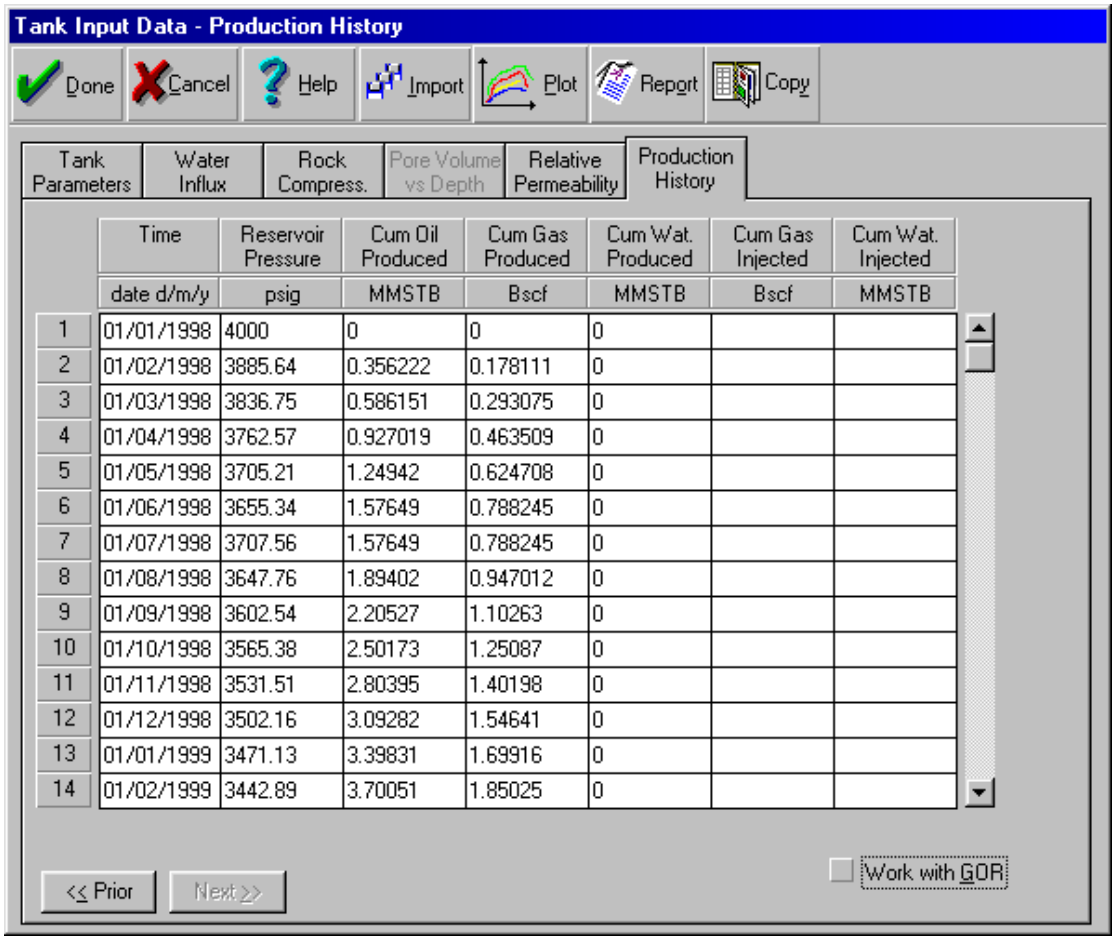


Figure 164: Tank input screen – Relative permeability

You also enter water and gas sweep efficiency values in this screen. These values are used to find the velocity at which the OWC and GOC contact move, when the monitor contacts option is selected.

The last data that we have to supply is the production history of the reservoir as shown in the following screen. Note that this can be copied from the Excel file OILRES1.XLS.



	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected
	date d/m/y	psig	MMSTB	Bscf	MMSTB	Bscf	MMSTB
1	01/01/1998	4000	0	0	0		
2	01/02/1998	3885.64	0.356222	0.178111	0		
3	01/03/1998	3836.75	0.586151	0.293075	0		
4	01/04/1998	3762.57	0.927019	0.463509	0		
5	01/05/1998	3705.21	1.24942	0.624708	0		
6	01/06/1998	3655.34	1.57649	0.788245	0		
7	01/07/1998	3707.56	1.57649	0.788245	0		
8	01/08/1998	3647.76	1.89402	0.947012	0		
9	01/09/1998	3602.54	2.20527	1.10263	0		
10	01/10/1998	3565.38	2.50173	1.25087	0		
11	01/11/1998	3531.51	2.80395	1.40198	0		
12	01/12/1998	3502.16	3.09282	1.54641	0		
13	01/01/1999	3471.13	3.39831	1.69916	0		
14	01/02/1999	3442.89	3.70051	1.85025	0		

Figure 165: Tank input screen – History matching

At this stage we have specified all the input data to the reservoir and we should check if everything is in order. To do so, if we go to the main screen menu and select **Input | System summary** the following screen appears and tells us if we have any missing or invalid data entry. In this case everything is okay.

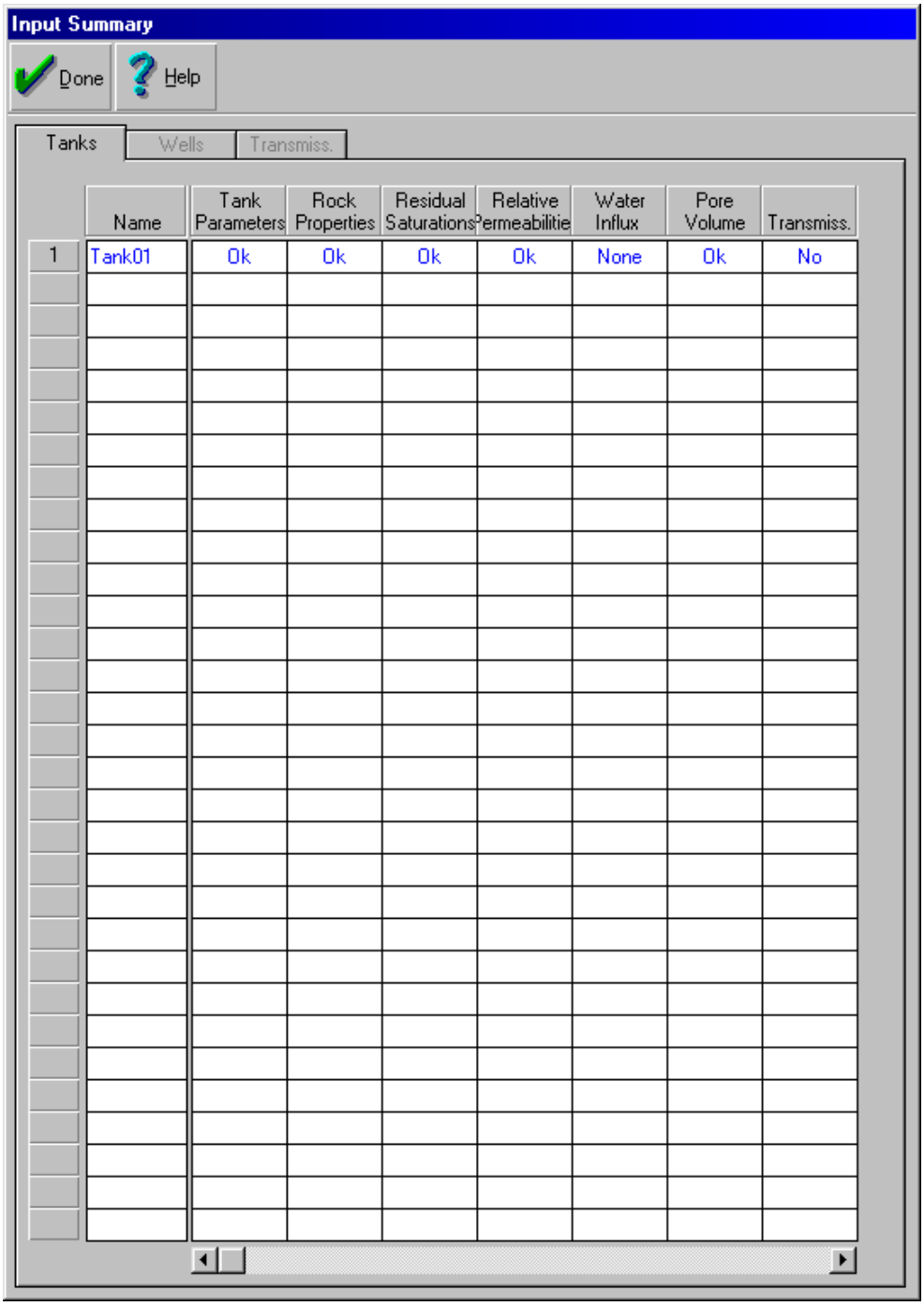
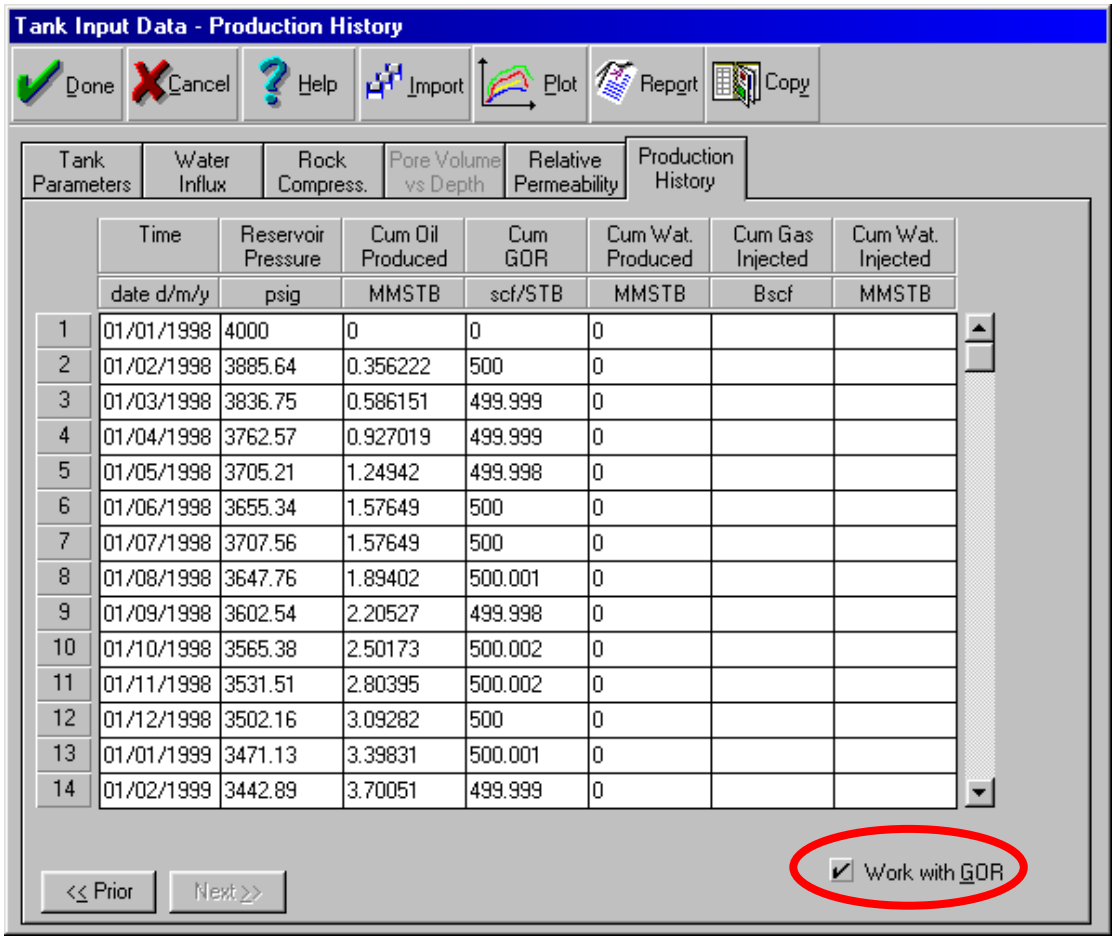


Figure 166: Tank input summary

This finishes our setting up of basic tank model. It is advisable to save the file at this point. Next step would be to fine-tune the model, in terms of identifying and quantifying its various drive mechanisms.

3.4.3 Matching to Production History data in MBAL

The first thing to do is to see whether our production history data is consistent with our **PVT** data. In the **PVT** section we indicated that the bubble point was 2200 psig and the solution GOR was 500 Scf/STB. If we go to the production history screen in the tank input data, we can click on the option **Work with GOR** at the bottom of the dialog and the gas rates are converted into producing GOR values.



	Time	Reservoir Pressure	Cum Oil Produced	Cum GOR	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected
	date d/m/y	psig	MMSTB	scf/STB	MMSTB	Bscf	MMSTB
1	01/01/1998	4000	0	0	0		
2	01/02/1998	3885.64	0.356222	500	0		
3	01/03/1998	3836.75	0.586151	499.999	0		
4	01/04/1998	3762.57	0.927019	499.999	0		
5	01/05/1998	3705.21	1.24942	499.998	0		
6	01/06/1998	3655.34	1.57649	500	0		
7	01/07/1998	3707.56	1.57649	500	0		
8	01/08/1998	3647.76	1.89402	500.001	0		
9	01/09/1998	3602.54	2.20527	499.998	0		
10	01/10/1998	3565.38	2.50173	500.002	0		
11	01/11/1998	3531.51	2.80395	500.002	0		
12	01/12/1998	3502.16	3.09282	500	0		
13	01/01/1999	3471.13	3.39831	500.001	0		
14	01/02/1999	3442.89	3.70051	499.999	0		

Figure 167: Checking consistency of data

In the production history, if you scroll down on this screen, you will see that the reservoir pressure is always above 2200 psig. Thus there is no free gas in the tank and hence the producing GOR should be the one coming from solution. Indeed in this case all the gas rates covert into GOR values which are nearly 500 SCF/STB. Thus the data is consistent with the **PVT**. In case it is not so, we need to go back to **PVT** or source of production data and try find the reason for the anomaly.

Once we are sure that the production history data is consistent with the **PVT**, the next step is to see how the model that we have set up compares to the history data. At this stage it is important to note that we are after a model which performs well on each method and not only on some. Thus we should start with History Matching | All. This produces the following plots.

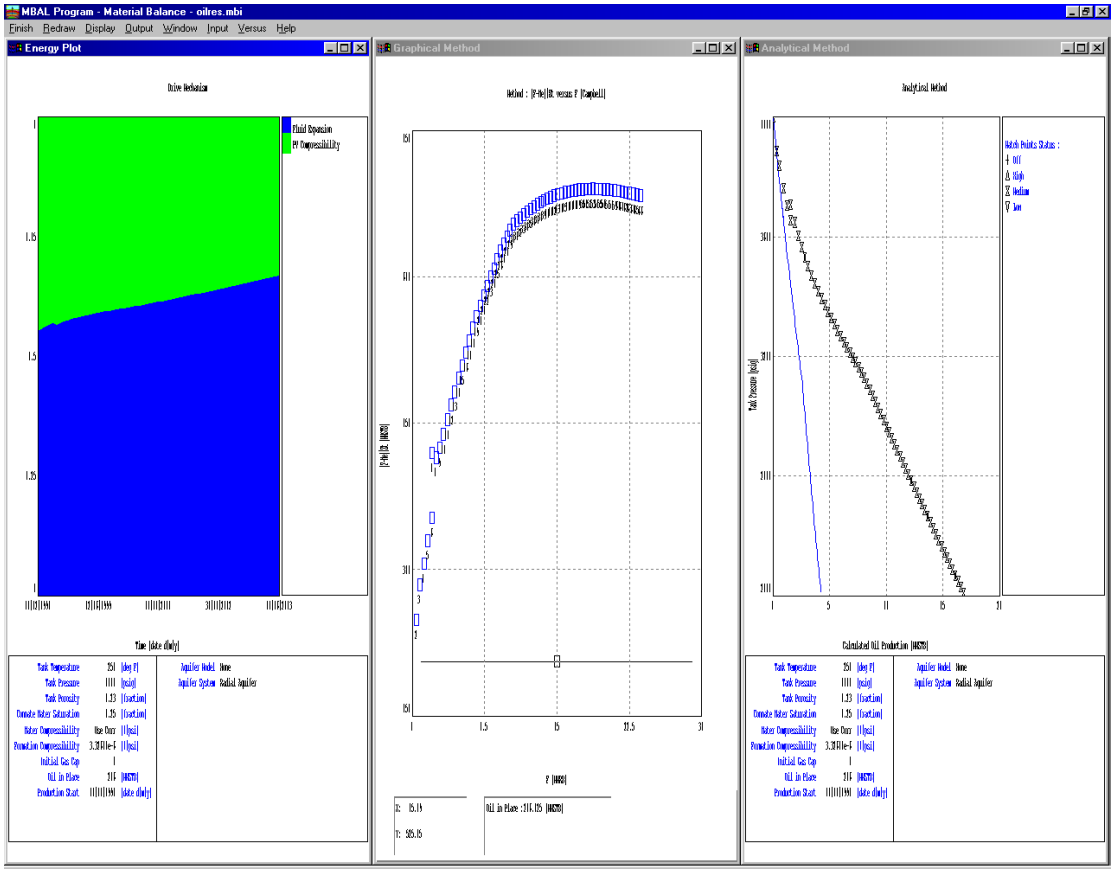

MBAL Program - Material Balance - oilres.mbi
Finish Redraw Display Output Window Input Versus Help
Energy Plot
Graphical Method
Analytical Method

Figure 168: History matching

Note that in the graphical methods the plot shown in the screen above is the Campbell plot. You may not get this initially. You should click on the graphical method screen and in the menu bar of the above screen as shown appears. Select **Method | Campbell Plot**.

The first plot is called the energy plot. It indicates contribution of various drive mechanisms towards production with time.

The second plot is the Campbell plot, which is a graphical technique used to find oil in place given a production history and known drive mechanisms (diagnostics).

The last plot is the analytical plot. On the y-axis of the analytical plot is the tank pressure and on the x-axis is the primary phase production (in this case oil). The data points are the actual pressures with oil production that we have entered in the history. The blue line indicates the response of the model according to the data entered in the Tank Data screen.

Based on the response of the Campbell plot, the presence of an aquifer is very likely (source of energy). Therefore an aquifer model can be selected in the tank data section:

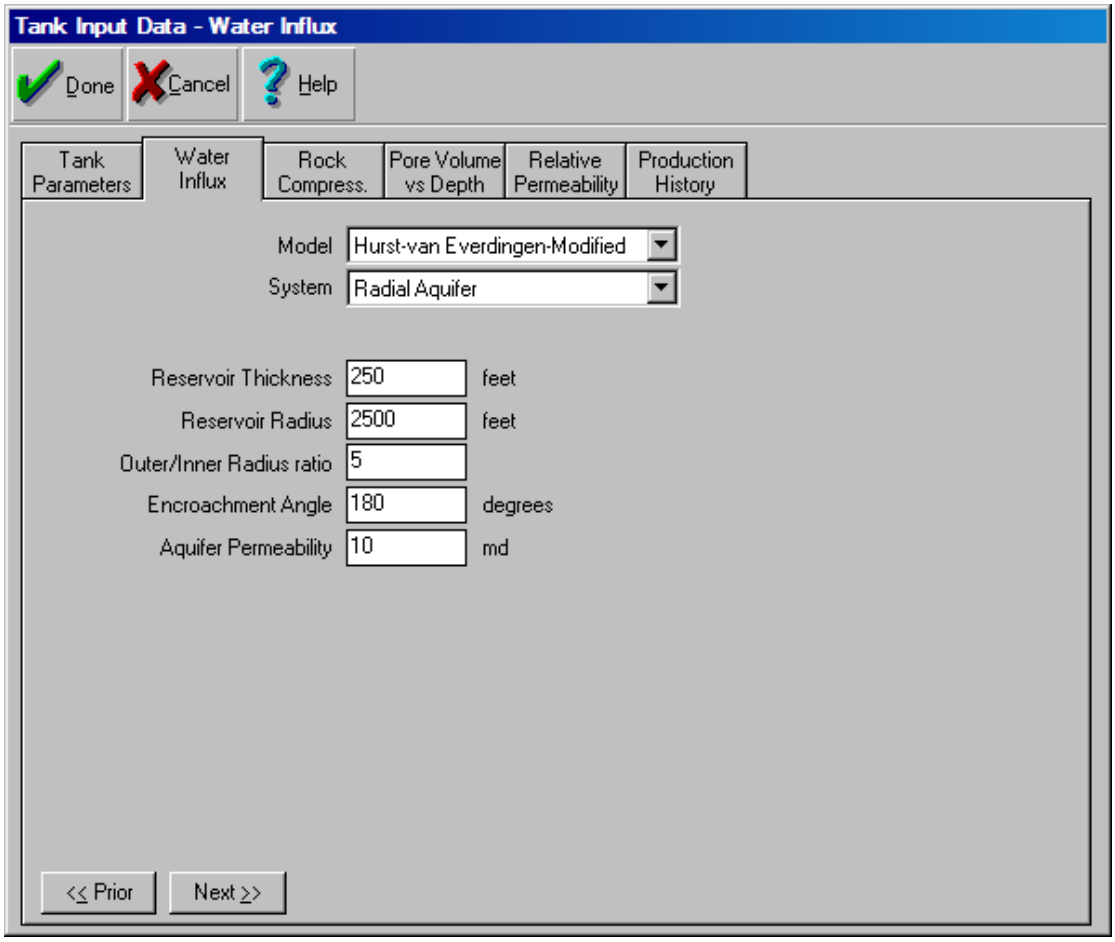


Figure 169: Initialising an aquifer model

Going back to History Matching/All:

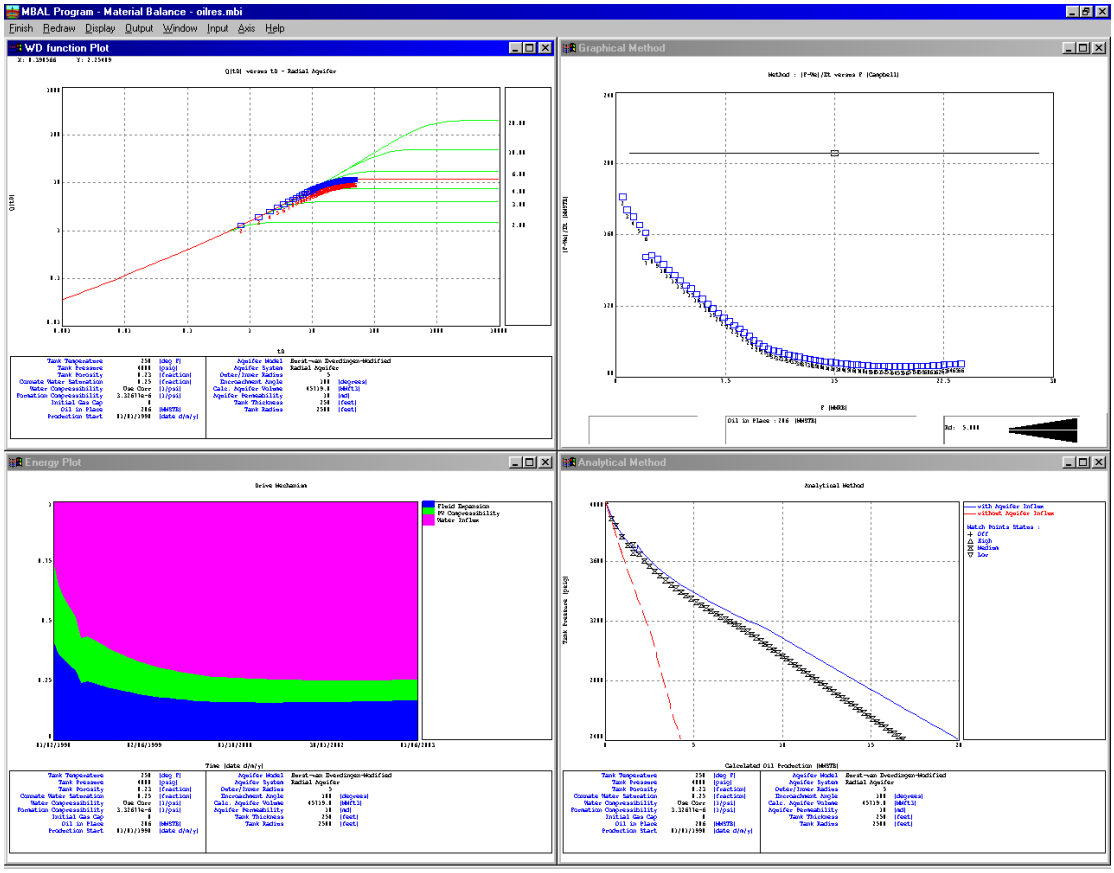

MBAL Program - Material Balance - oilres.mbi
Finish Redraw Display Output Window Input Axis Help
WD function Plot
Graphical Method
Energy Plot
Analytical Method

Figure 170: History matching plots

If we look at the analytical plot, it indicates that with the current aquifer model, we are predicting production rates higher than those actually observed. Thus we may have a weaker aquifer. We can decrease the strength of the aquifer either by accessing on the tool bar of the previous screen **Input | Tank data** and decreasing the aquifer inner to outer radius ratio (r_D). We can accomplish the same, in the WD plot of the above screen, if we double click at a the smaller r_D value of 4.0, as indicated in the plot below, so that on the analytical plot the actual history points and the solid line come closer as shown below.

Figure 171: History Matching Plot

At this stage if you look at the analytical plot, we can see that the match we are getting is quite good. On this plot the model selected and the history entered seem to be in good agreement with each other. But on the other hand, the model we have selected does not fit well on the Campbell plot, where ideally we should get a horizontal straight line. This is the reason that we recommended at the start that while doing history match, all the screens should be used simultaneously and a model that fares well according to all different methods be used.

At the end of this step we are very close to representing the reservoir behaviour and we can fine-tune it by doing a regression analysis. To activate regression analysis button, we have to click on the analytical plot and in the menu bar of the above screen select **Regression**, which will activate the following screen

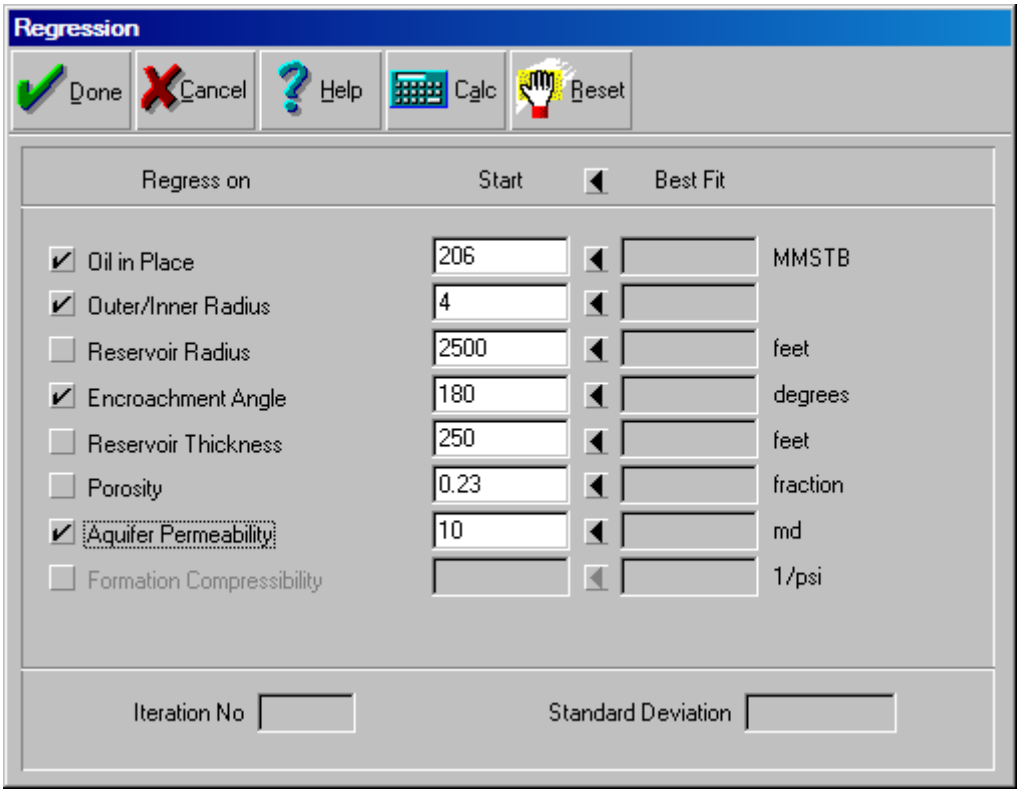


Figure 172: Regression

In all of the variables we can change on the above screen, we select the parameters that influence aquifer behaviour and the OIP itself. This is a good choice for this case because from the energy plot we see that these are the two major components of the energy of the system. We do not change the compressiblity because we believe the correlations do a good job for this case.

At the end of regression we get the following best match.

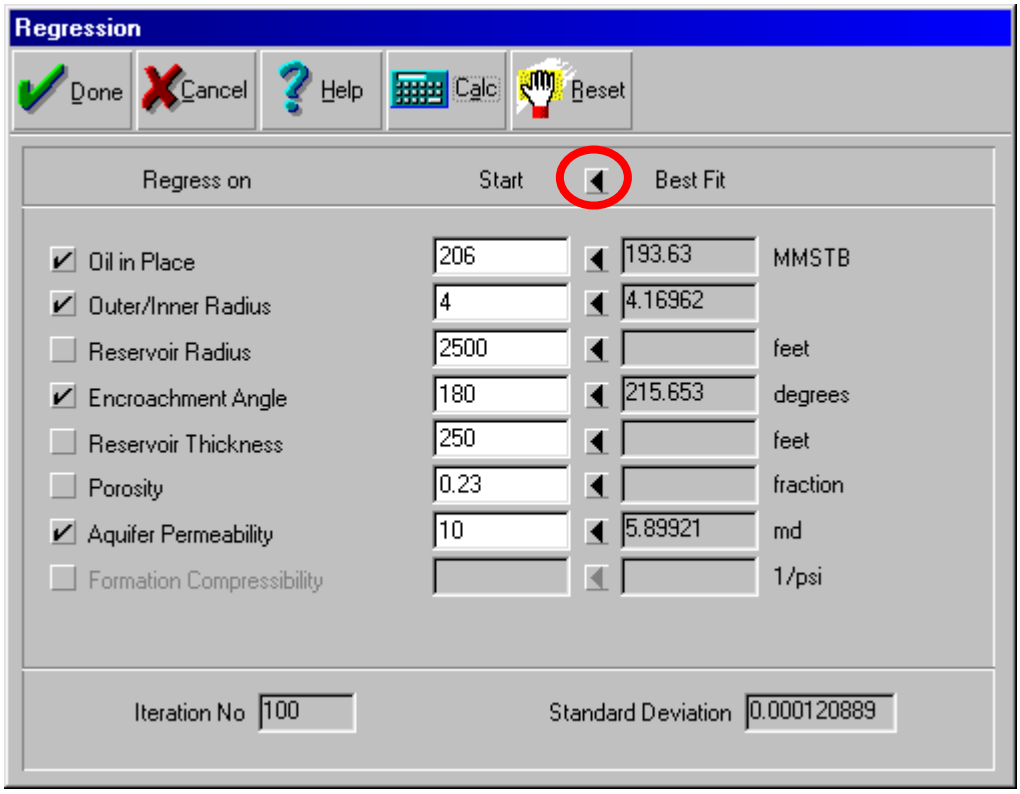


Figure 173: Transferring the regressed data

Once the regression is finished, the best fit data should transferred to start column by clicking on the transfer button which is the arrow button between the **Start** and **Best Fit** text.

After transferring the data if we click on **Done** we get the following plots:

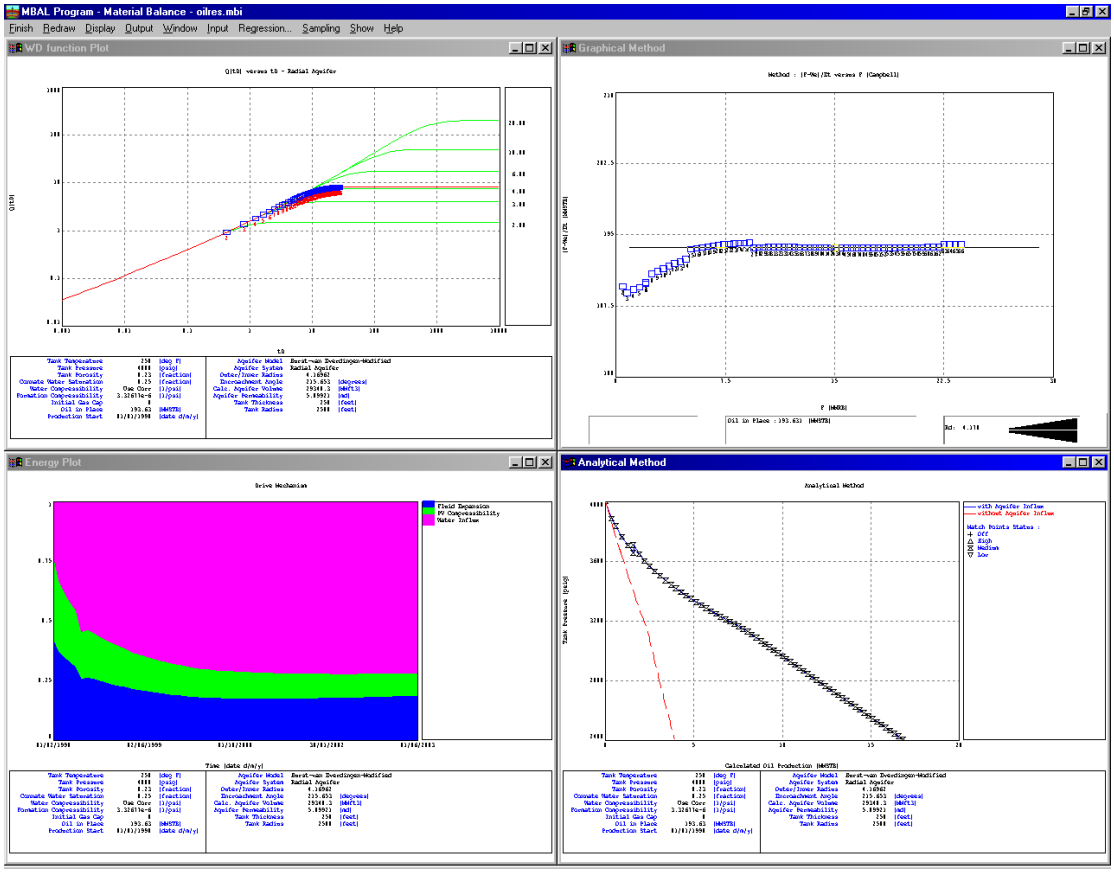

MBAL Program - Material Balance - oilres.mbi
Finish Redraw Display Output Window Input Regression... Sampling Show Help
WD function Plot
Graphical Method
Energy Plot
Analytical Method

Figure 174: History matching done

The model got at this stage in terms of OIP and various drive mechanisms seems to satisfy all the methods and is thus acceptable

Save the file as **Oilres.mbi**.

3.4.4 Running Sensitivity Analysis on the Tank Model

Once at the end of history matching we have selected a model in terms of OIP and various drive mechanisms, it is important that we do some sort of analysis on the figures we have arrived at check our confidence in these figures. This is allowed by doing a sensitivity analysis on the model. In sensitivity analysis what we do is that we try to see how sensitive is our model to the change in parameters that we have fixed by history match.

If we go to the main menu and select **History Match | Sensitivity** the following screen appears. In this case we want to study the effect of changing the OIP place only. We are trying to see the effect of changing it between the values of 180 and 250.

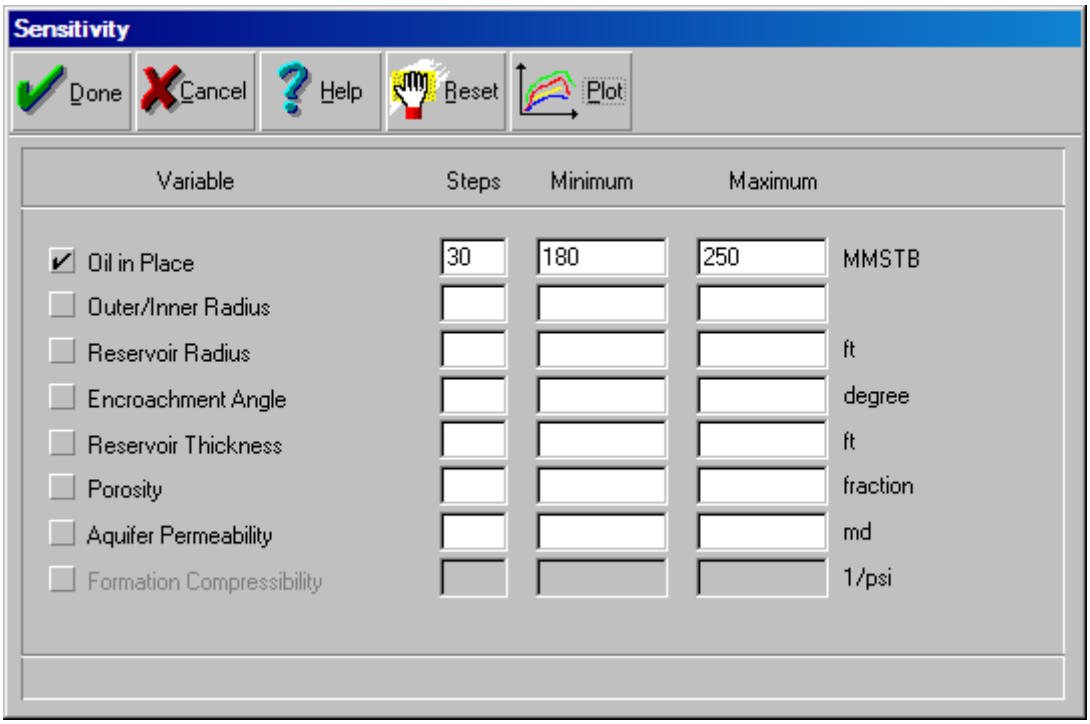


Figure 175: Sensitivity

On this screen if the “Plot” button is selected, the following plot is obtained.

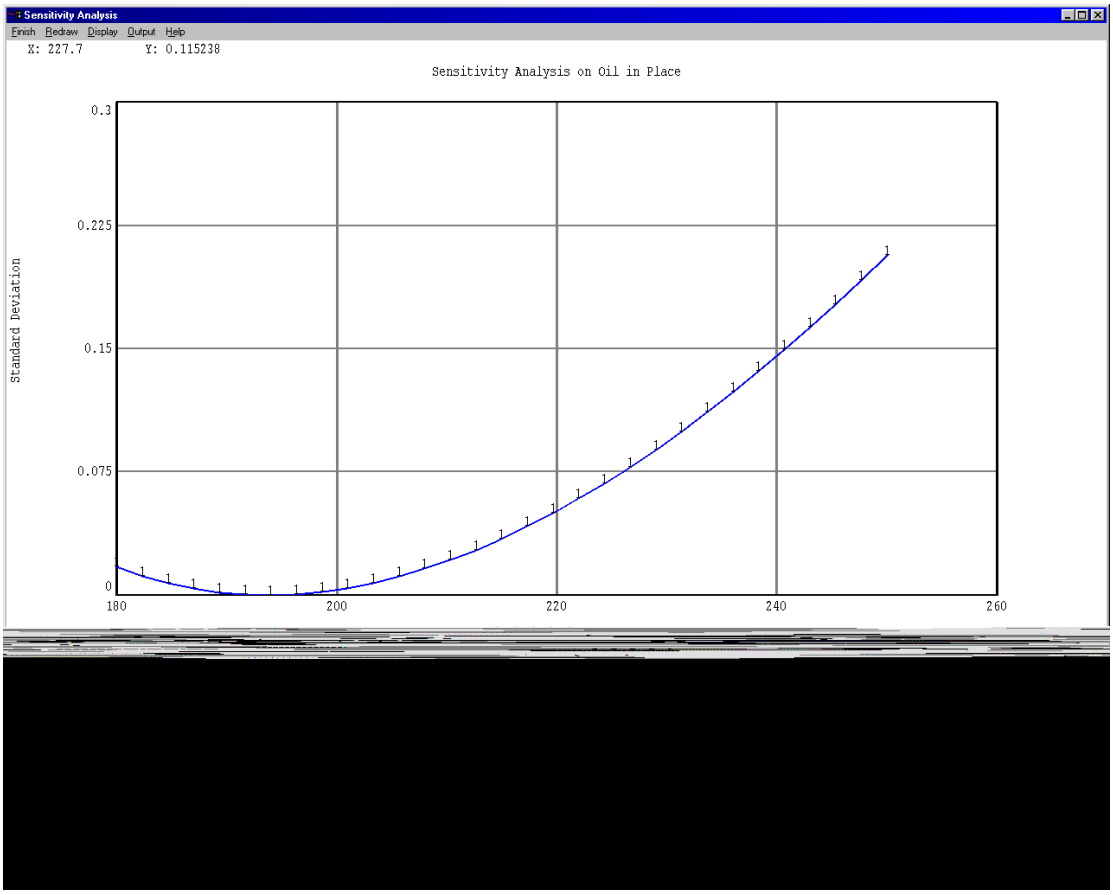


Figure 176: Sensitivity plot

On the x-axis is the OIP and on the y-axis is the standard deviation in terms of predicted production rates over the history. The presence of a minimum shows the uniqness of the solution.

We can similarly do sensitivity analysis on other drive mechanisms like the aquifer parameters for this case and find about our confidence in those figures as well.

3.4.5 Using Simulation Option to Quality check the History Matched Model

At the end of running sensitivity analysis the next step we have identified our confidence in the drive mechanisms. At this stage it must be noted that in the regression analysis that we did in analytical plot, we take the tank pressure and non primary phase production and with the model calculate the error in production rate of primary phase, oil in this case.

In simulation what we do is exactly opposite. With the given model we have fixed we take all the phase rates from the history and try to predict the pressure, phase saturation in the tank and other tank parameters. If our model is acceptable the last test it should satisfy is that it should be able to reproduce pressure as well.

If in the main menu we select **History Matching | Run simulation | Calculate** , the program does calculations. At the end of calculation if you hit Plot, the following plot appears:-

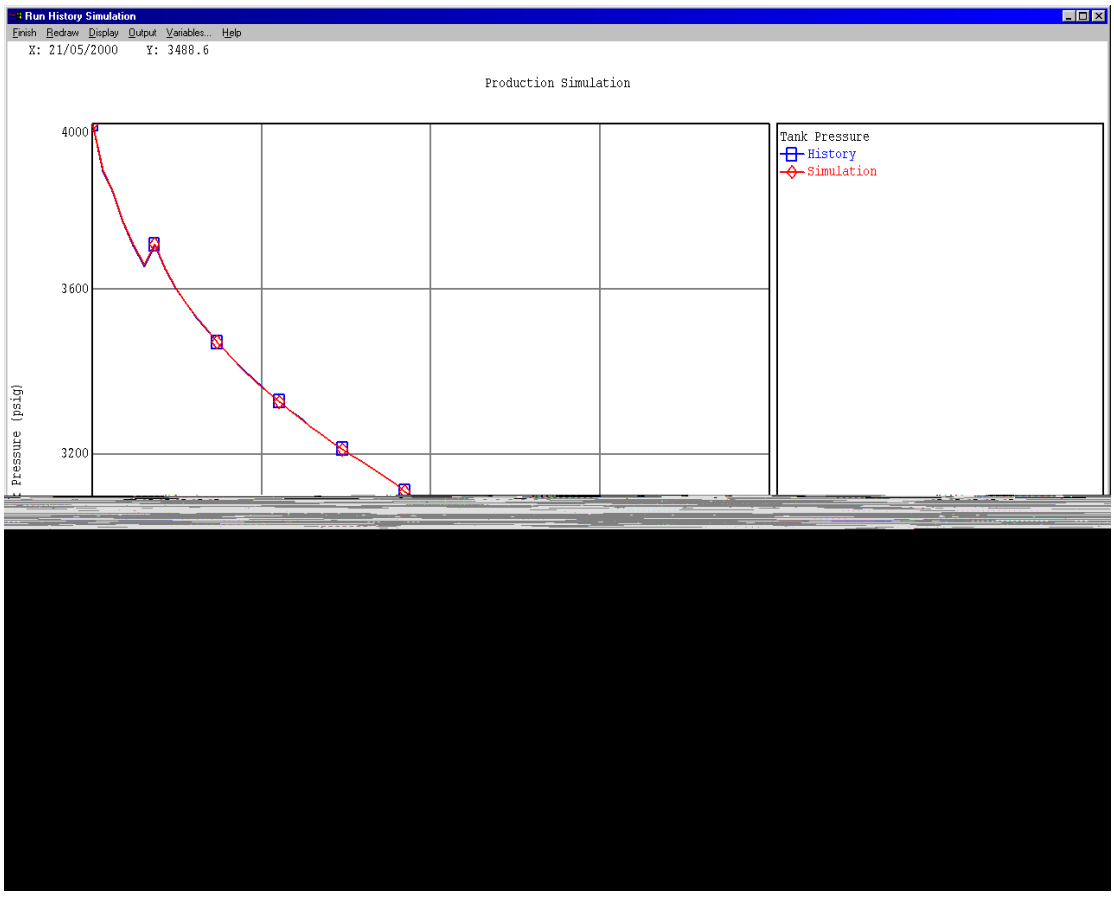


Figure 177: Comparison between simulation and history

This plot has the pressure with time plotted both from simulation and production history data. In this case both are identical and thus the match attained is good.

Note: The model is not ready at this stage to go ahead with predictions and study various development alternatives. Fractional flow matching in order to create pseudo relative permeability curves should be done and also the verification of these as demonstrate in the previous example.

3.5 Performing a Production Prediction starting from a history matched model

The following example shows how to perform prediction runs with **MBAL**.
The file **GasTank1.mbi** has already been history matched.
In order to follow this example, first you would need to launch **MBAL** and then recall the **MBAL** file:

*C:\Program Files\Petroleum Experts\IPM4.0\Samples**MBAL**\GasTank1.mbi*

Statement of the problem

An **MBAL** model has been created and history match performed. It will be used to generate production predictions for two cases:
Case 1: Follow the current production pattern – WHFP = 800 psig
Case 2: Reduce the well head pressure to 100 psig from 01/01/2004

Input Data

Well Inflow Data

In this example, the well Inflow is represented by the C & n model. Any sophisticated IPR model can be collapsed to the C & n method. For more details on Inflow models, please refer to **PROSPER**, the well bore modelling package.

Well Name	C- factor (Mscf/d/psi^2)	N-Exponent
Producer#1	0.027	0.85
Producer#2	0.002	0.95
Producer#3	0.005	0.9

Generic Well Outflow tables:

In this example, it will be assumed that all wells have the same lift tables.
Lift tables can be generated with **PROSPER** and then imported in **MBAL**. They have already been prepared and can be found in:
*C:\Program Files\Program Files\Petroleum experts\IPM4.0\Samples**MBAL**\GasTank Well Lift Tables.TPD*

Cases to study

Case 1: WHFP = 800 psig

Case 2: WHFP is reduced to 100 psig from 01/01/2004 by installing a compressor in the field.

Step-by-Step procedure for a prediction run with MBAL

Step 1: Prediction set-up
In order to perform a prediction, select |Production Prediction |Prediction Setup and make the following changes:

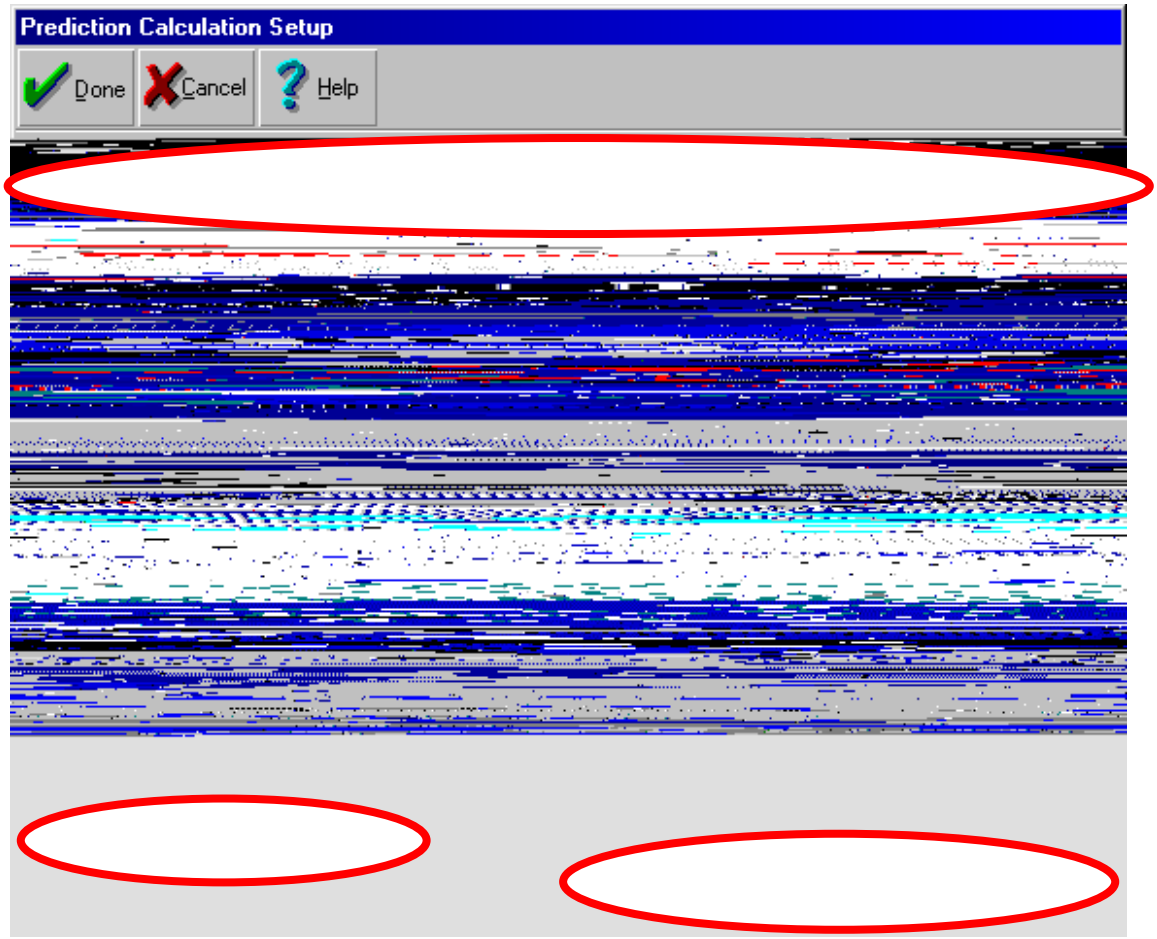


Figure 178: Prediction Calculation Setup

Select |Done to complete this.

Step 2: Boundary conditions at surface
Now select |Production Prediction|Production and Constraints and enter date and Manifold Pressure as shown in the screenshot below:

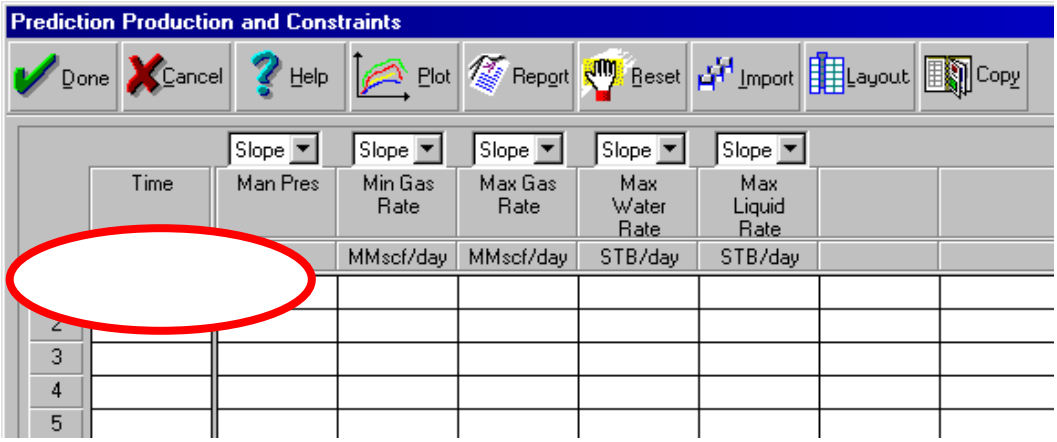


Figure 179: Prediction Production and Constraints

The manifold pressure is the pressure in the node furthest from the sandface in the well model used to generate the lift tables. In this example, the manifold pressure is the well head pressure.

Now select |Done to complete this.

Step 3: Well Type Definition
Each well is defined by a VLP and an IPR. VLP stands for vertical lift performance, whereas IPR stands for Inflow Performance Relationship.
Select |Production Prediction|Well Type Definition, the following screen is accessed:

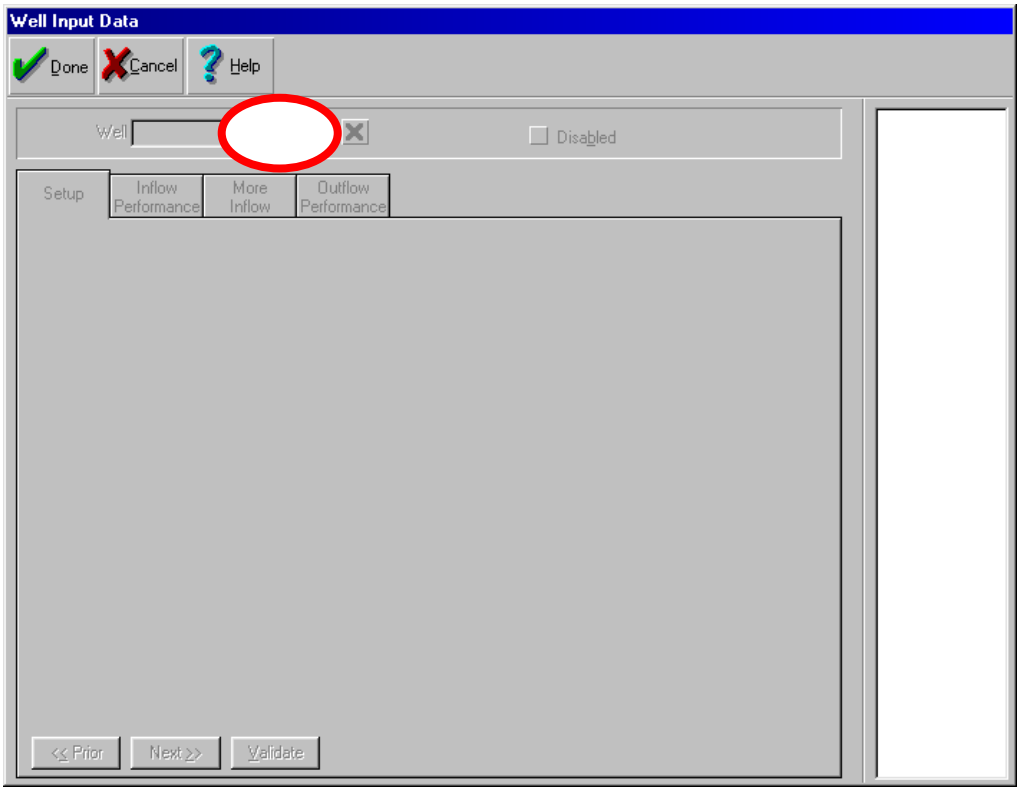


Figure 180: Well Input Data

Clicking on the “ ” button, a well is created with the default name “Well1” that can be overwritten.
Here we will overwrite the default well name with “Producer#1P”

Make sure that the well type is correct. Here the well type is “Dry Gas Producer”.
This is how the screen looks like:

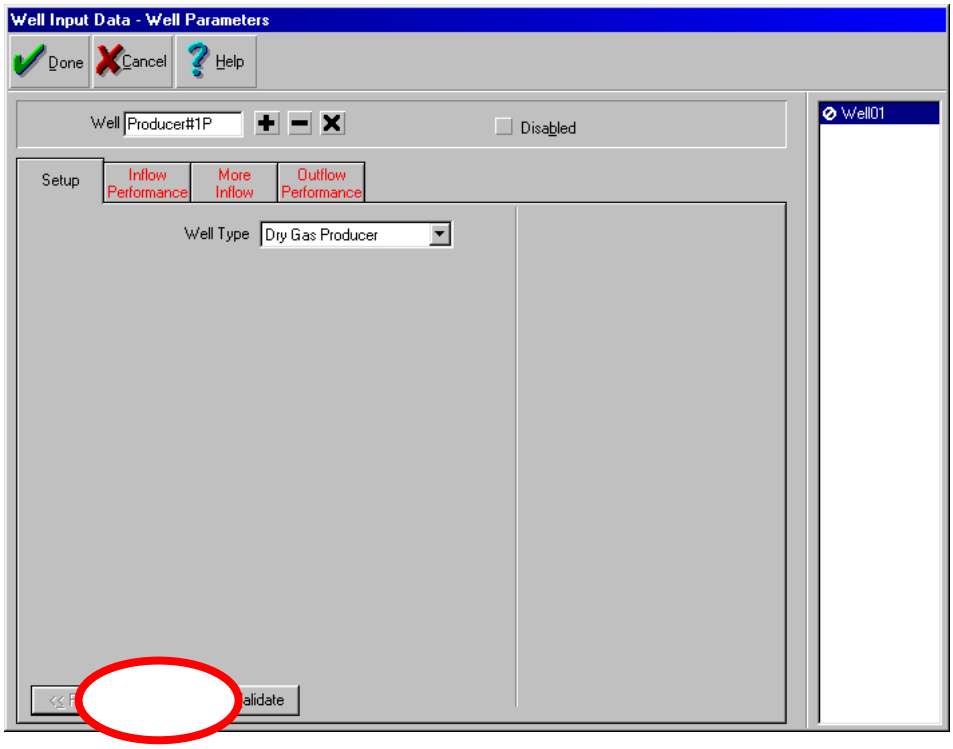


Figure 181: Well Input Data

Select the Next button to proceed to the Inflow section.

Step 4: Inflow Performance Tab
Once entered the Inflow tab screen, make the following changes:

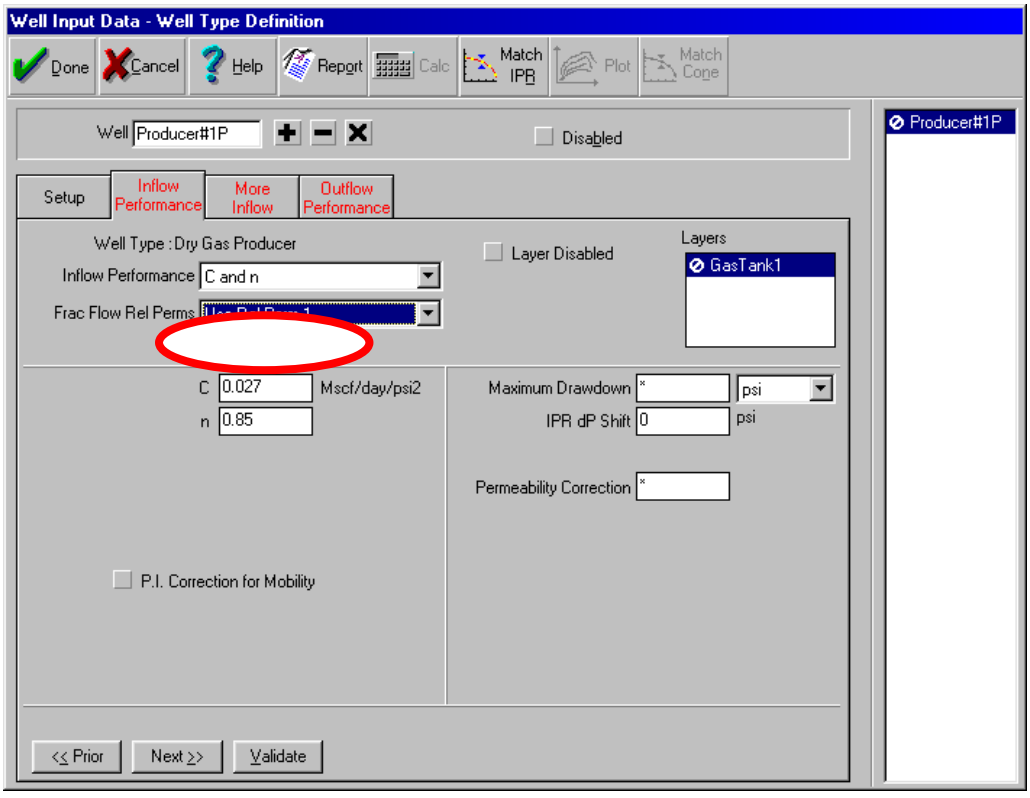


Figure 182: Well Inflow Data

To assign the relative permeabilities derived during the fractional flow matching, select |Edit|Copy. In this way, a list of all permeability tables available in the **MBAL** model is displayed:

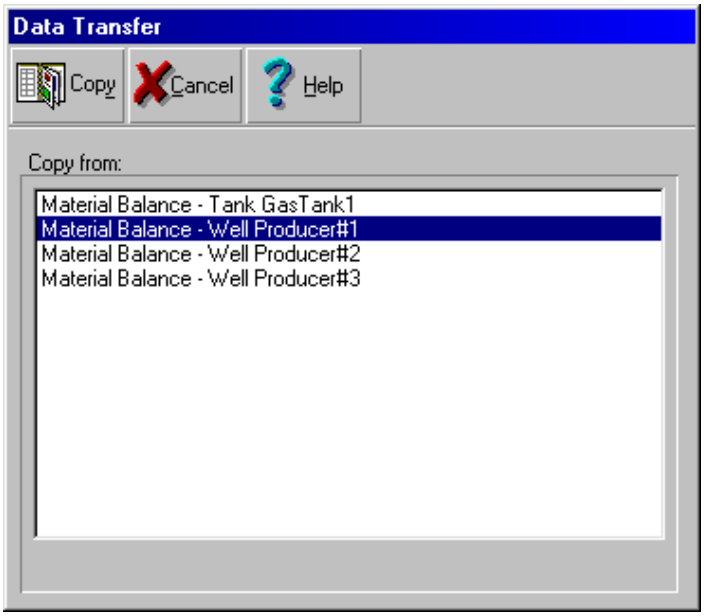


Figure 183: Relative Permeability Data Transfer

Here select the appropriate one and then select |Copy and then the Corey parameters are assigned to the well.
Now click on |Done. **MBAL** will ask if the water breakthrough saturation is to be copied:

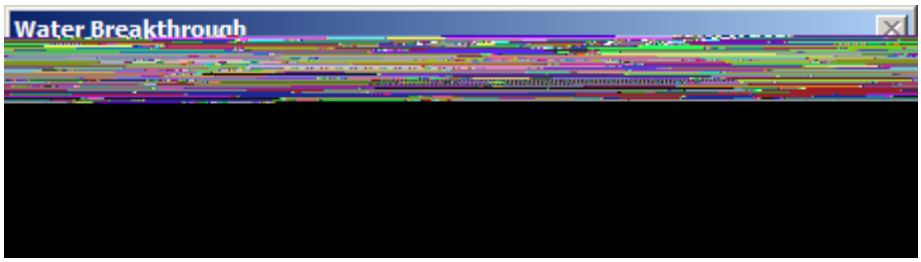


Figure 184: Water Breakthrough copy

Now select |Yes to continue with |Next|Next (skipping the More Inflow).

Note: How to derive relative permeability curves by fractional flow matching:
After running a simulation, select History Matching | Fw Matching from the main menu toolbar. The follow plot is displayed:

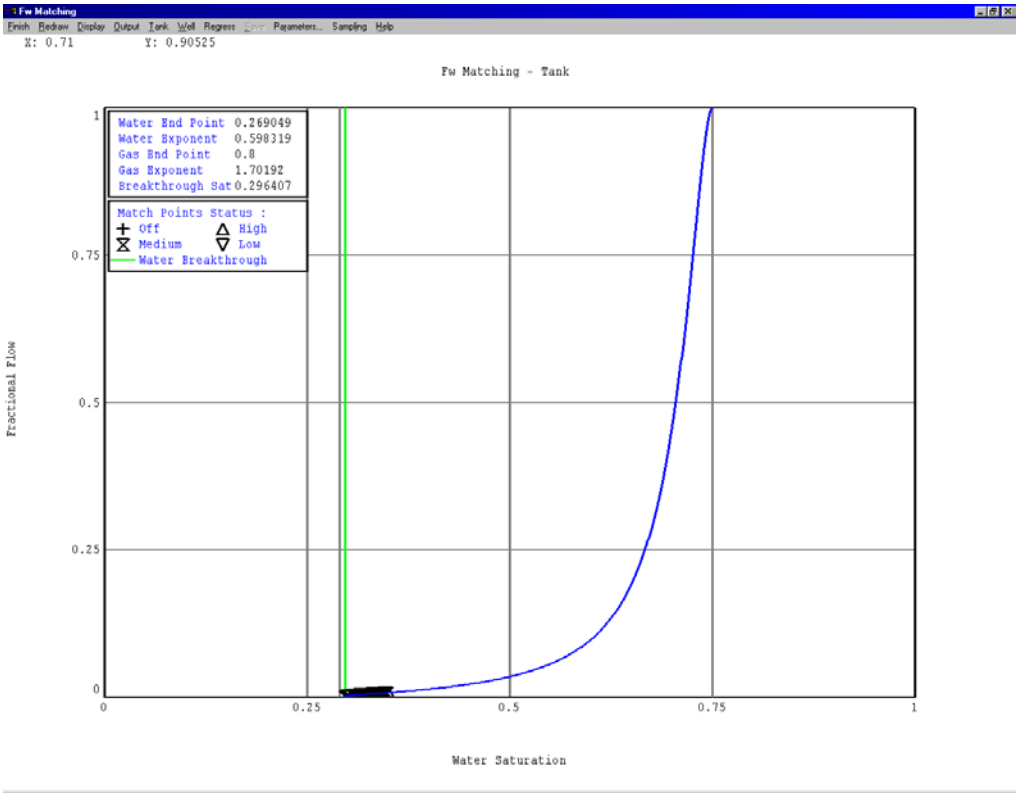


Figure 185: Fw Matching plot

From the menu toolbar of the plot screen, select Well, and then the well to match, for example Producer#1:

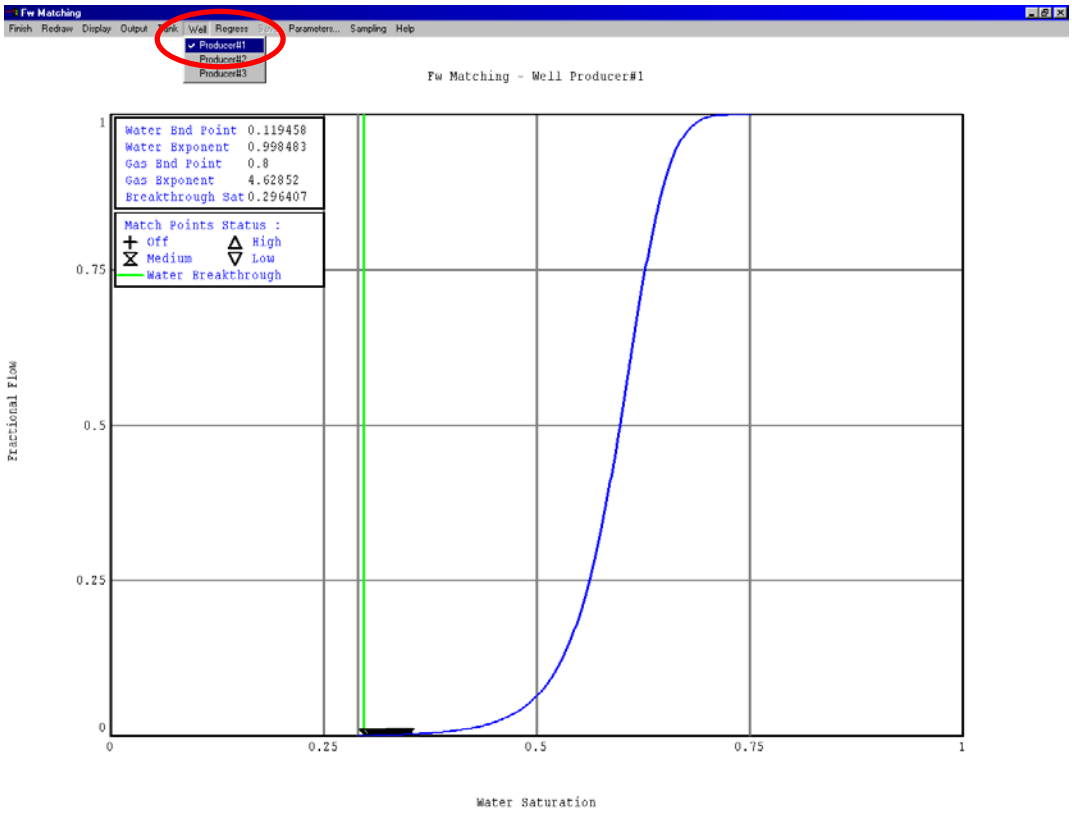


Figure 186: Fw Matching plot

In the plot area, double click on a point corresponding to the desired breakthrough water saturation (for example the minimum water saturation, which is 0.29 in this case). After that, click on Regress, so that the program can perform a regression to fit the points calculated by the simulation, and a set of Corey function parameters are calculated, which give the same fractional flow.

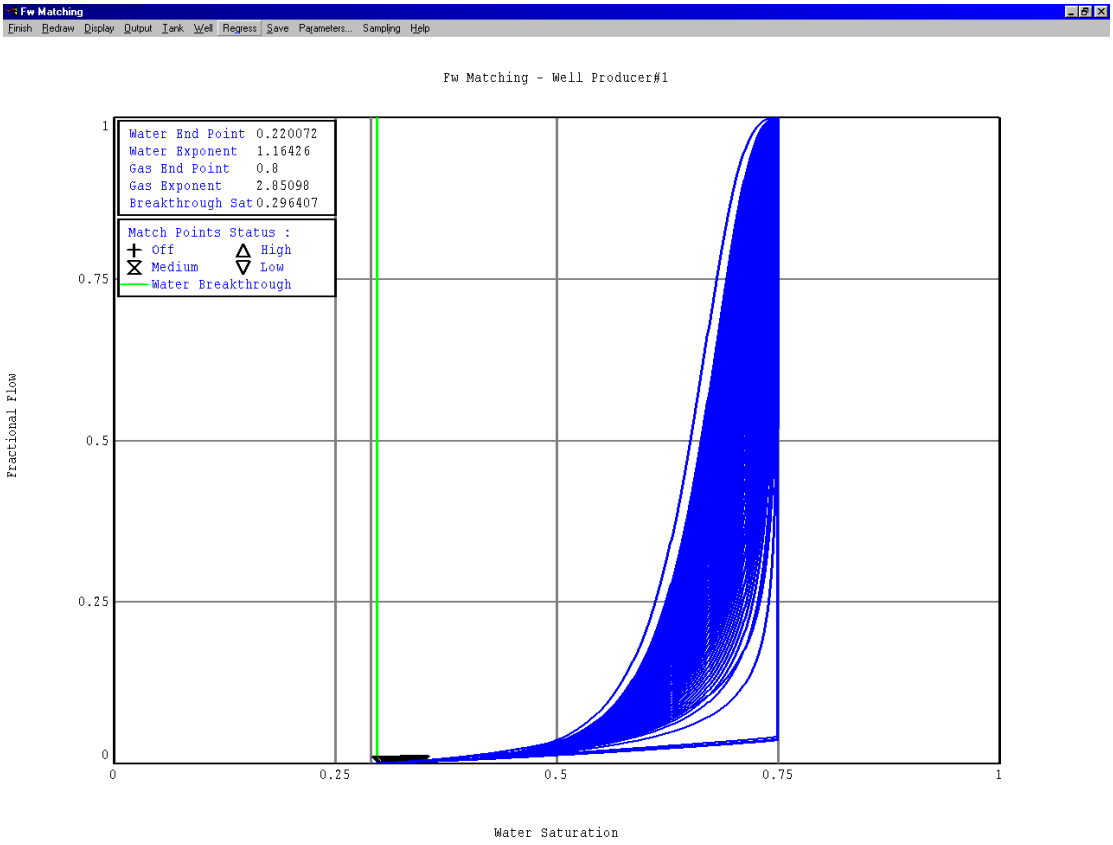


Figure 187: Fw Matching plot while performing regression

Step 5: Lift tables import

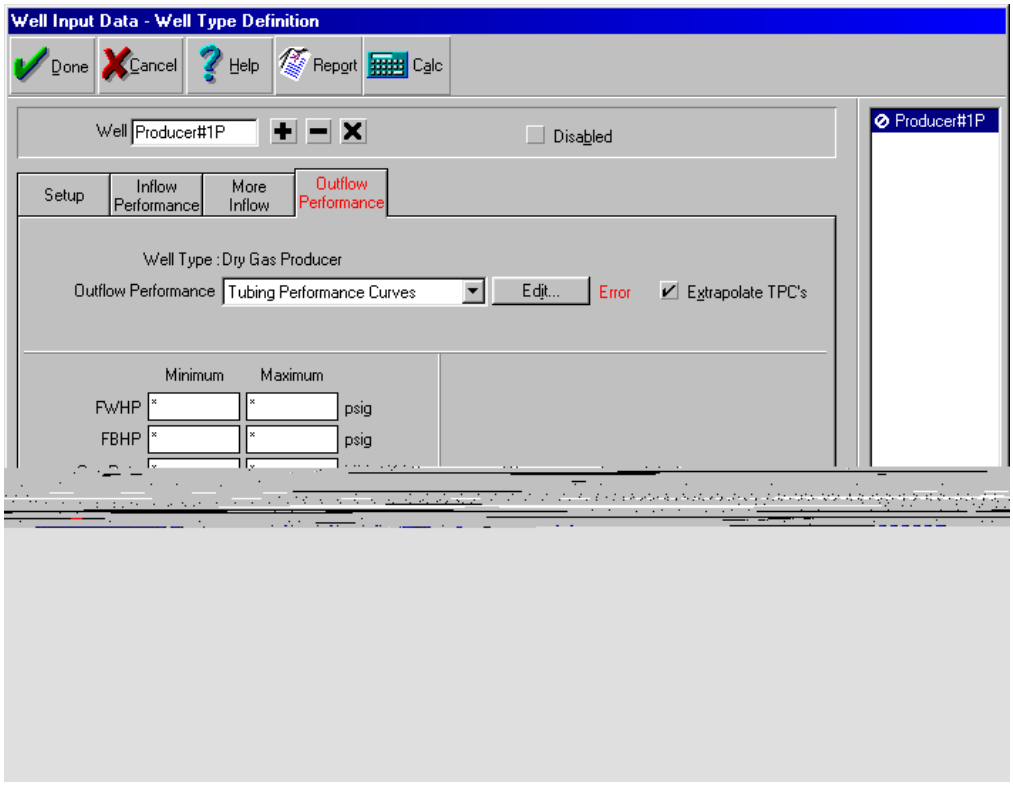


Figure 188: Well Outflow Data

In this screen click on the |Edit button and then select |Import. Using the browser, import the TPD file provided.
TPD files are lift tables files for Petroleum Experts applications (***GAP***, ***REVEAL***, ***MBAL***).

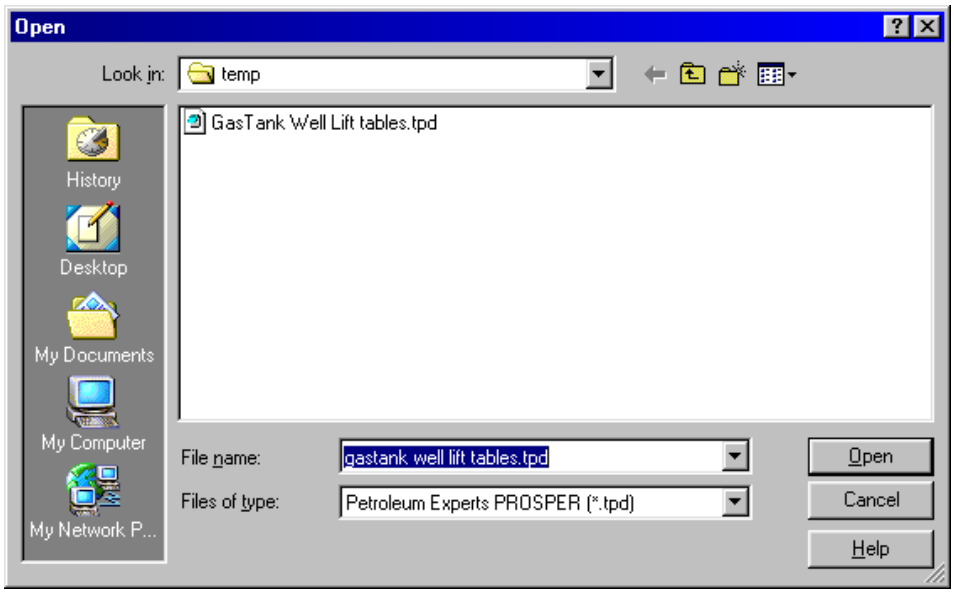


Figure 189: TPD file import

Clicking on |Open, a statistics about the flow tables is shown:

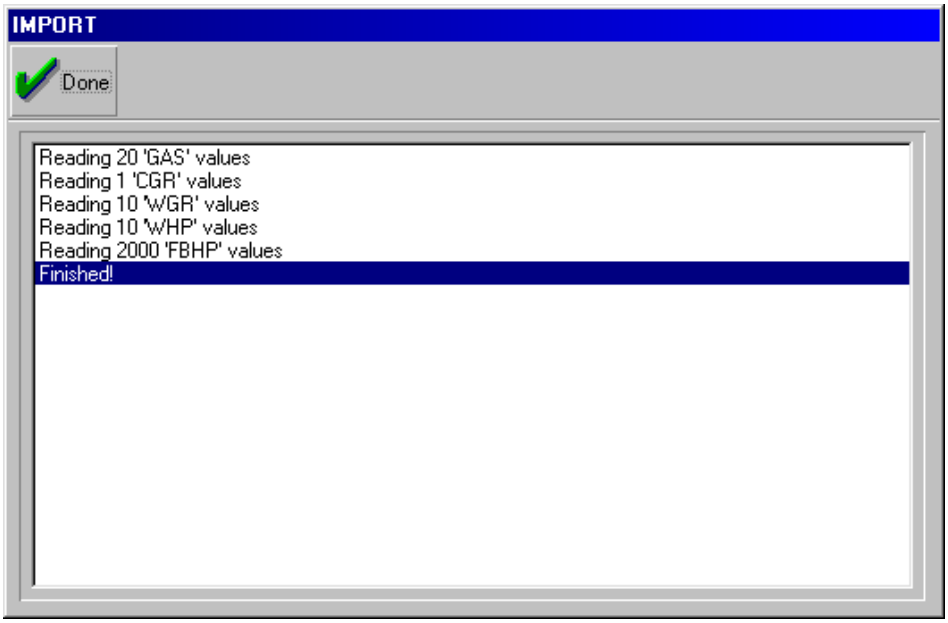


Figure 190: TPD file import

Select |Done and this completes the setup of this well.
Repeat the same process for all the 3 wells.
This is how the main screen will look like:

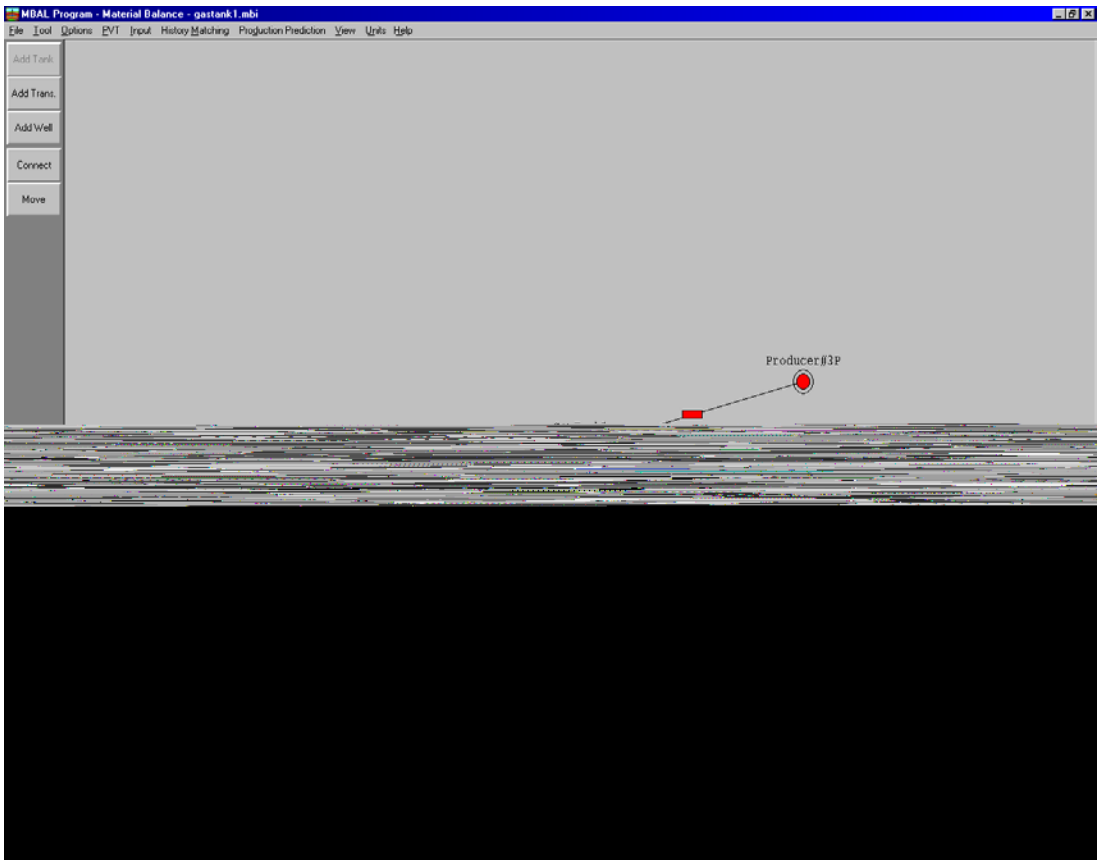


Figure 191: MBAL final model

Step 6: Well scheduling.

In order to schedule the wells, select |Production Prediction|Well Schedule and make the following changes:

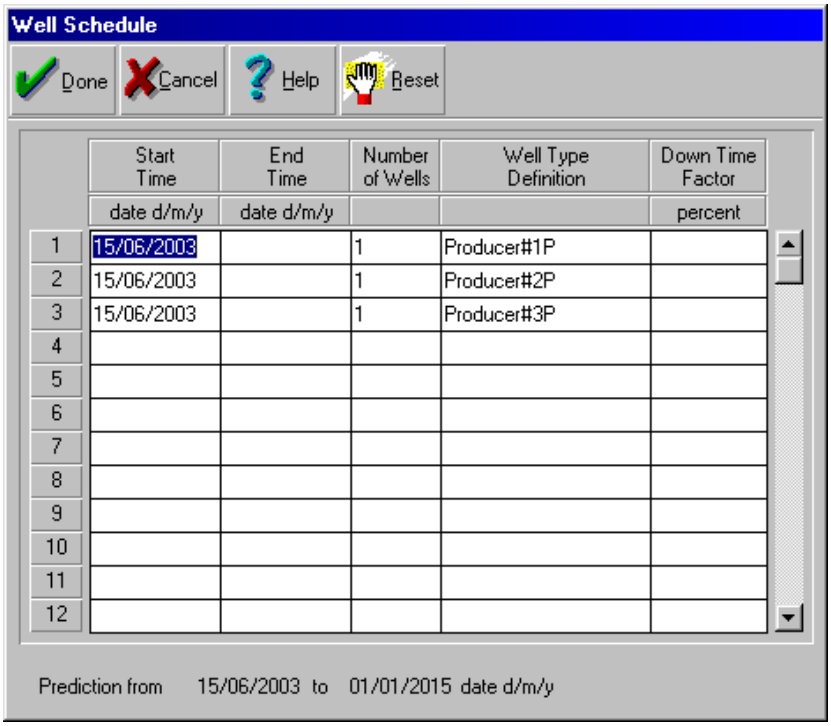


Figure 192: Well Schedule

Click on |Done to validate the screen.

Step 7: Reporting schedule

For this example, select |Production Prediction|Reporting Schedule and make the following changes:

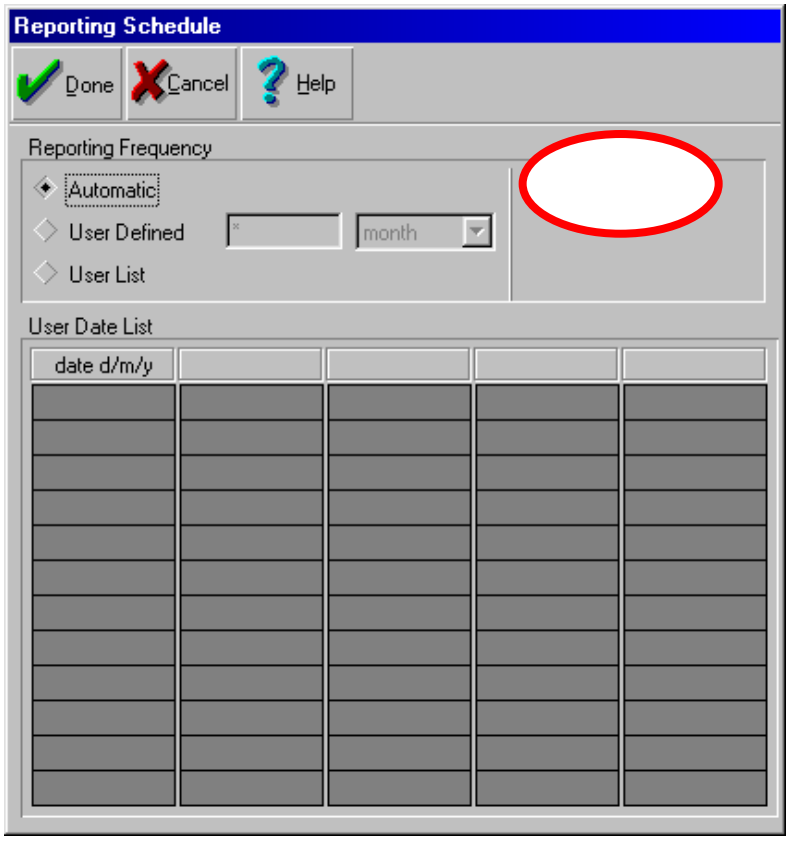
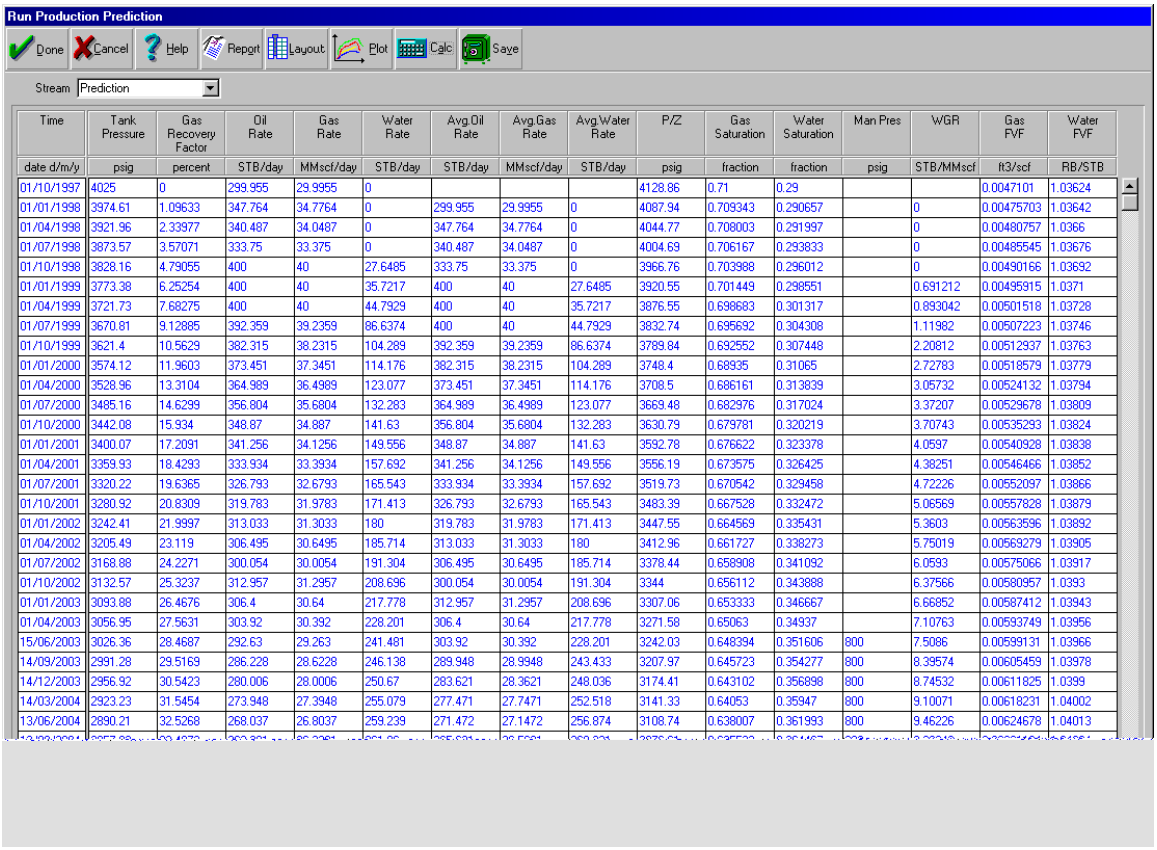


Figure 193: Reporting Schedule

The “Keep History” button allows to have the full history stream along with the prediction stream for comparison purposes. Keep Automatic Reporting Frequency and click on Done to exit the screen.

Step 8: Running the prediction

Choose |Production Prediction|Run Prediction|Calculate, then Ok. The results of the calculation are displayed:



Time	Tank Pressure	Gas Recovery Factor	Oil Rate	Gas Rate	Water Rate	Avg Oil Rate	Avg Gas Rate	Avg Water Rate	P/Z	Gas Saturation	Water Saturation	Man Pres	WGR	Gas FVF	Water FVF
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	STB/day	MMscf/day	STB/day	psig	fraction	fraction	psig	STB/MMscf	ft3/scf	RB/STB
01/10/1997	4025	0	299.955	29.9955	0				4128.86	0.71	0.29		0	0.0047101	1.03624
01/01/1998	3974.61	1.09633	347.764	34.7764	0	299.955	29.9955	0	4087.94	0.709343	0.290657		0	0.00475703	1.03642
01/04/1998	3921.96	2.33977	340.487	34.0487	0	347.764	34.7764	0	4044.77	0.708003	0.291997		0	0.00480757	1.0366
01/07/1998	3873.57	3.57071	333.75	33.375	0	340.487	34.0487	0	4004.69	0.706167	0.293833		0	0.00485545	1.03676
01/10/1998	3828.16	4.79055	400	40	27.6485	333.75	33.375	0	3966.76	0.703988	0.296012		0	0.00490166	1.03692
01/01/1999	3773.38	6.25254	400	40	35.7217	400	40	27.6485	3920.55	0.701449	0.298551		0.691212	0.00495915	1.0371
01/04/1999	3721.73	7.68275	400	40	44.7929	400	40	35.7217	3876.55	0.698683	0.301317		0.893042	0.00501518	1.03728
01/07/1999	3670.81	9.12885	392.359	39.2359	86.6374	400	40	44.7929	3832.74	0.695692	0.304308		1.11982	0.00507223	1.03746
01/10/1999	3621.4	10.5629	382.315	38.2315	104.289	392.359	39.2359	86.6374	3789.84	0.692552	0.307448		2.20812	0.00512937	1.03763
01/01/2000	3574.12	11.9603	373.451	37.3451	114.176	382.315	38.2315	104.289	3748.4	0.68935	0.31065		2.72783	0.00518579	1.03779
01/04/2000	3528.96	13.3104	364.989	36.4989	123.077	373.451	37.3451	114.176	3708.5	0.686161	0.313839		3.05732	0.00524132	1.03794
01/07/2000	3485.16	14.6299	356.804	35.6804	132.283	364.989	36.4989	123.077	3669.48	0.682976	0.317024		3.37207	0.00529678	1.03809
01/10/2000	3442.08	15.934	348.87	34.887	141.63	356.804	35.6804	132.283	3630.79	0.679781	0.320219		3.70743	0.00535293	1.03824
01/01/2001	3400.07	17.2091	341.256	34.1256	149.556	348.87	34.887	141.63	3592.78	0.676622	0.323378		4.0597	0.00540928	1.03838
01/04/2001	3359.93	18.4293	333.934	33.3934	157.692	341.256	34.1256	149.556	3556.19	0.673575	0.326425		4.38251	0.00546466	1.03852
01/07/2001	3320.22	19.6365	326.793	32.6793	165.543	333.934	33.3934	157.692	3519.73	0.670542	0.329458		4.72226	0.00552097	1.03866
01/10/2001	3280.92	20.8309	319.783	31.9783	171.413	326.793	32.6793	165.543	3483.39	0.667528	0.332472		5.06569	0.00557828	1.03879
01/01/2002	3242.41	21.9997	313.033	31.3033	180	319.783	31.9783	171.413	3447.55	0.664569	0.335431		5.3603	0.00563596	1.03892
01/04/2002	3205.49	23.119	306.495	30.6495	185.714	313.033	31.3033	180	3412.96	0.661727	0.338273		5.75019	0.00569279	1.03905
01/07/2002	3168.88	24.2271	300.054	30.0054	191.304	306.495	30.6495	185.714	3378.44	0.658908	0.341092		6.0593	0.00575066	1.03917
01/10/2002	3132.57	25.3237	312.957	31.2957	208.696	300.054	30.0054	191.304	3344	0.656112	0.343888		6.37566	0.00580957	1.0393
01/01/2003	3093.88	26.4676	306.4	30.64	217.778	312.957	31.2957	208.696	3307.06	0.653333	0.346667		6.66852	0.00587412	1.03943
01/04/2003	3056.95	27.5631	303.92	30.392	228.201	306.4	30.64	217.778	3271.58	0.65063	0.34937		7.10763	0.00593749	1.03956
15/06/2003	3026.36	28.4687	292.63	29.263	241.481	303.92	30.392	228.201	3242.03	0.648394	0.351606	800	7.5086	0.00599131	1.03966
14/09/2003	2991.28	29.5169	286.228	28.6228	246.138	289.948	28.9948	243.433	3207.97	0.645723	0.354277	800	8.39574	0.00605459	1.03978
14/12/2003	2956.92	30.5423	280.006	28.0006	250.67	283.621	28.3621	248.036	3174.41	0.643102	0.356898	800	8.74532	0.00611825	1.0399
14/03/2004	2923.23	31.5454	273.948	27.3948	255.079	277.471	27.7471	252.518	3141.33	0.64053	0.35947	800	9.10071	0.00618231	1.04002
13/06/2004	2890.21	32.5268	268.037	26.8037	259.239	271.472	27.1472	256.874	3108.74	0.638007	0.361993	800	9.46226	0.00624678	1.04013

Figure 194: Run Production Prediction

Click on |Plot|Variables and make the following choices:

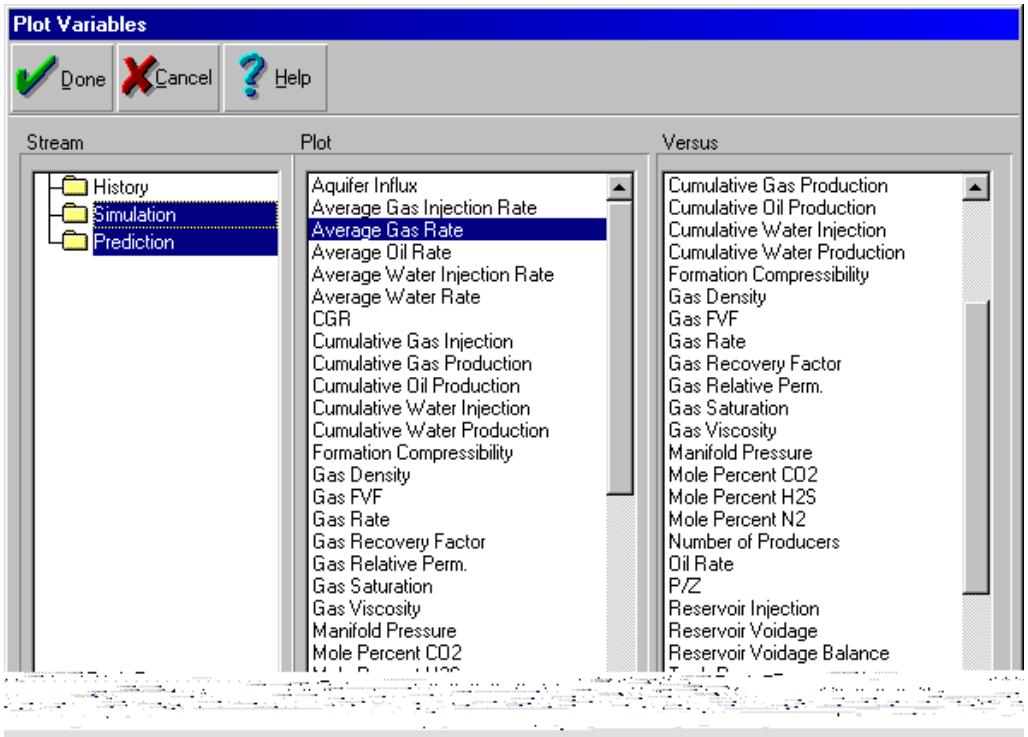


Figure 195: Plot Variables

Afterwards, click on |Done. The following plot is displayed:

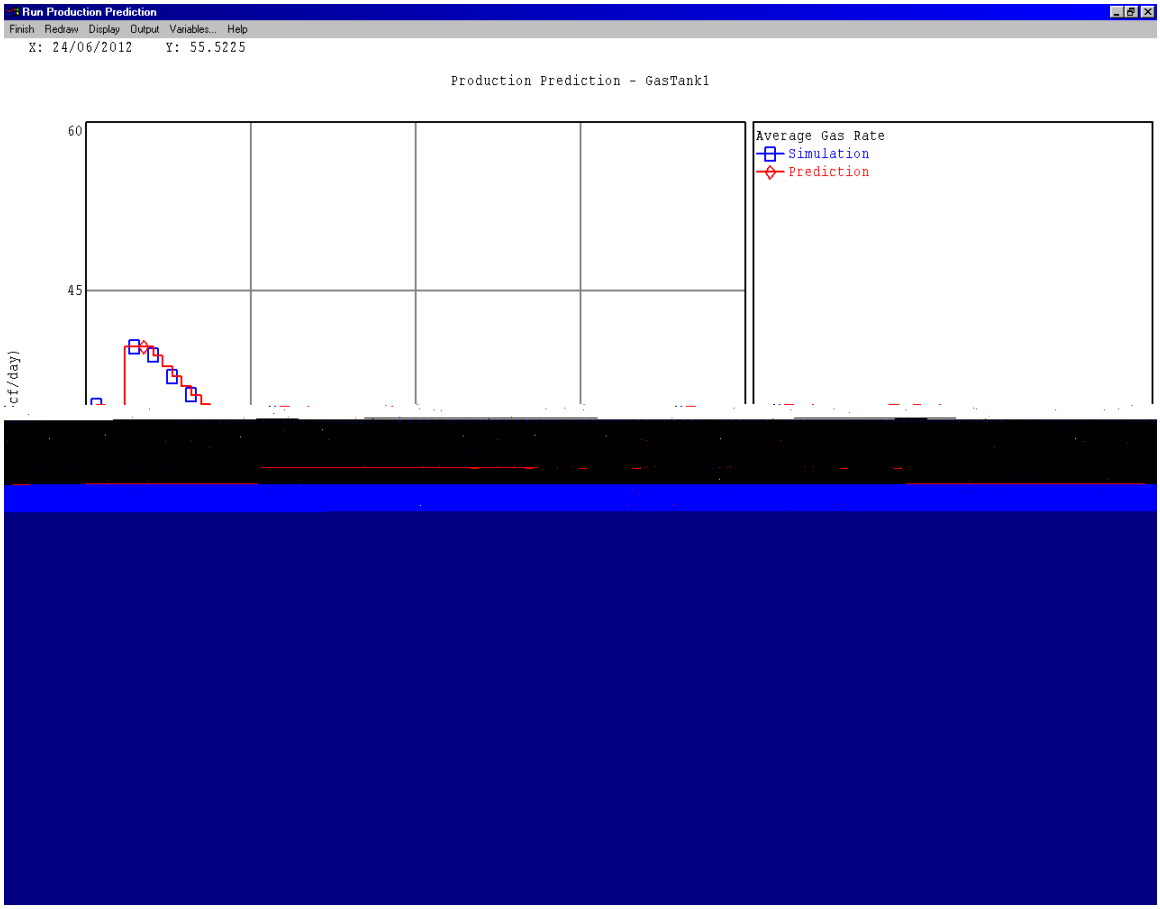


Figure 196: Average Gas Rate Plot

Now starting from this model it is possible to make forecasts on multiple field scenarios.

Step 9: Saving a case a stream within **MBAL**

From the plot toolbar choose |Finish. It is possible to save the results of each prediction, so that they can be reviewed later and compared to other scenarios.
In the Run Prediction screen, click on Save:

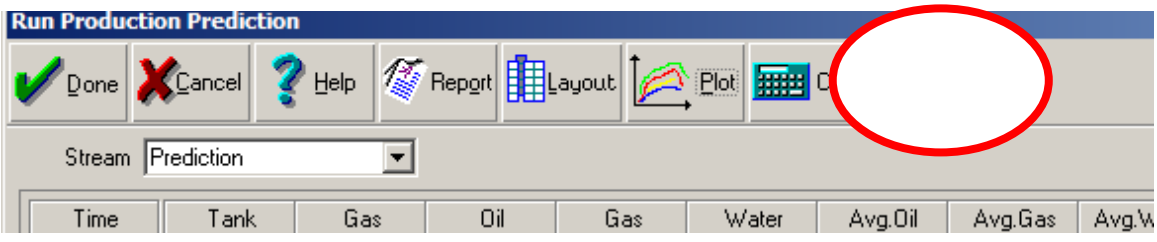


Figure 197: Save Prediction

Then click on|Add and overwrite the stream name as suggested below:

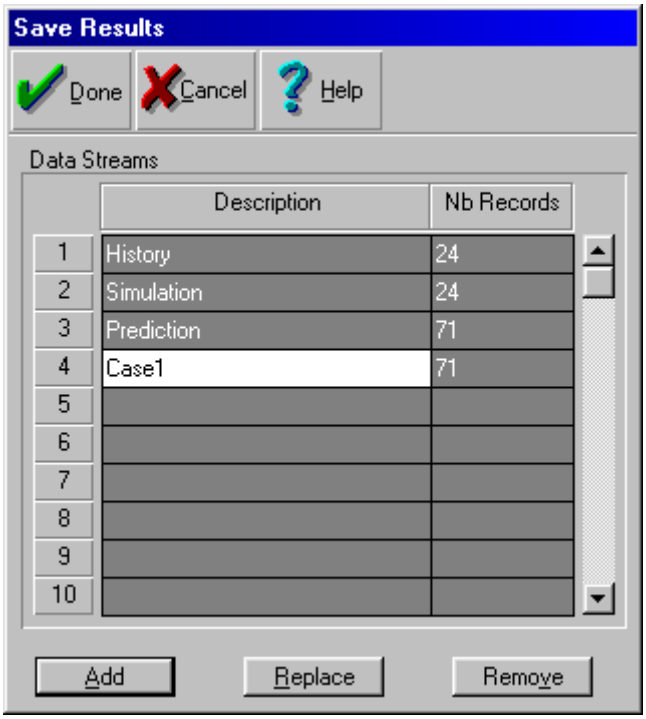


Figure 198: Save Results screen

Select |Done|Done to complete this.

Step 10: Second case
Choose |Production Prediction|Production and Constraints, and enter the new data for Case 2:

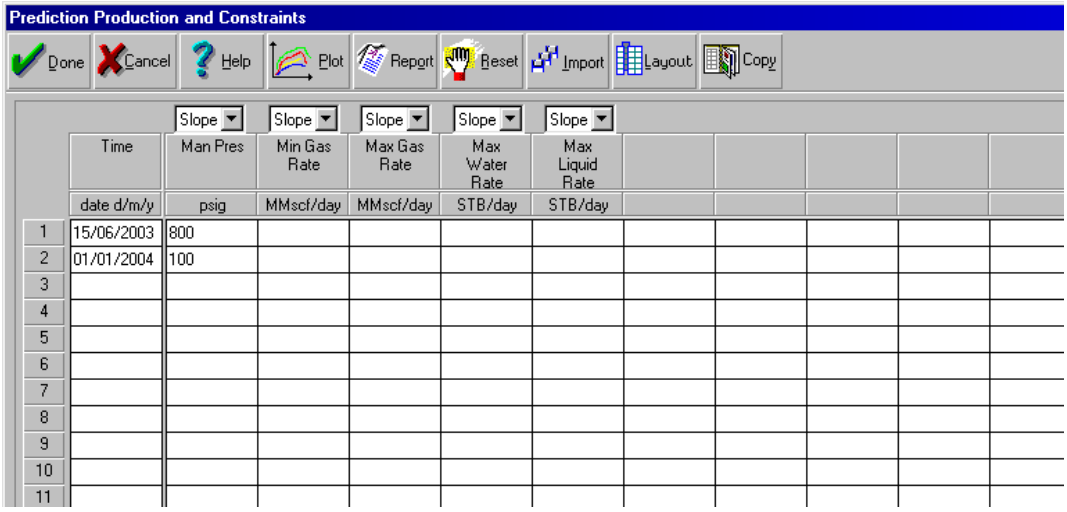


Figure 199: Prediction Production and Constraints

Select |Done to complete this.

Step 11: Generating the production profile
Choose |Production Prediction|Run Prediction|Calculate|Save |Add and name this stream “Case 2”:

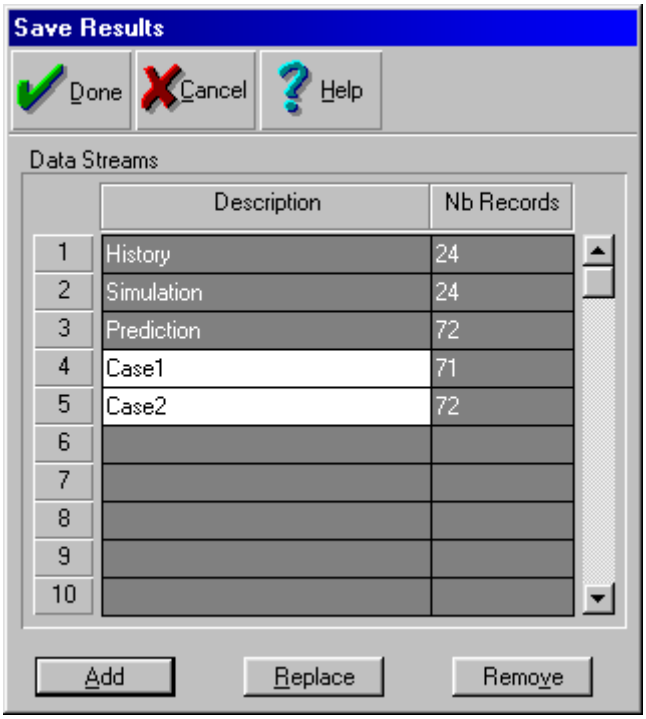


Figure 200: Save Results screen

After clicking on |Done and then |Plot|Variables, make the following selections, for instance:

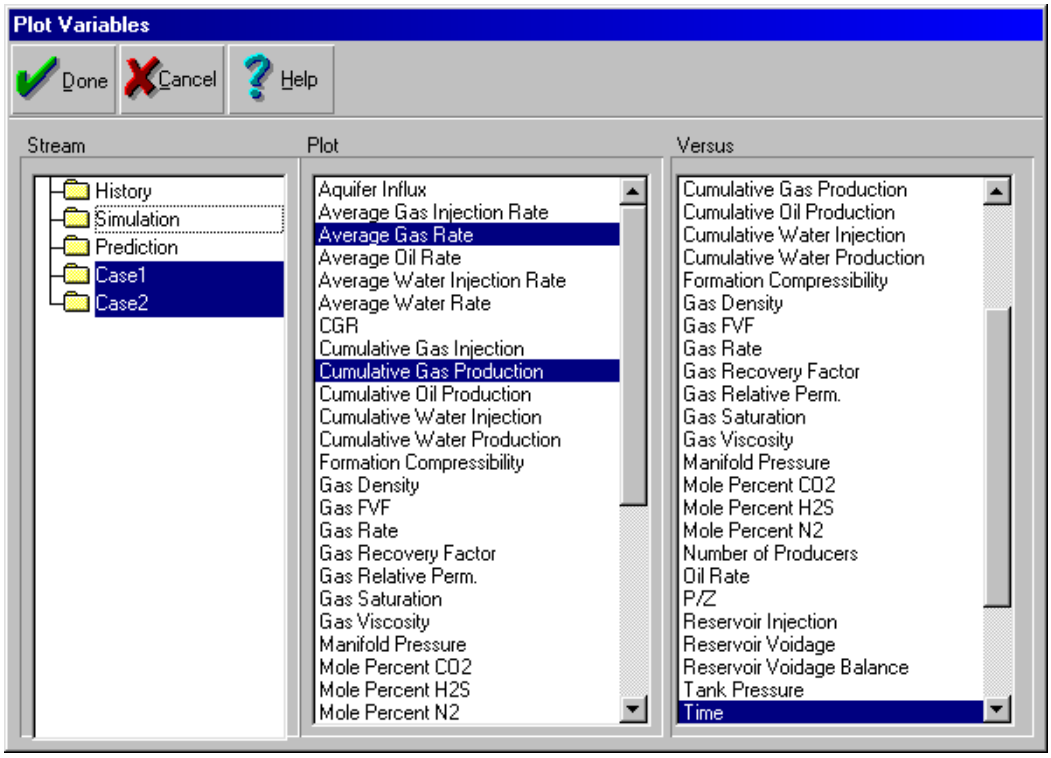


Figure 201: Plot Variables

Then |Done and the following plot is displayed:

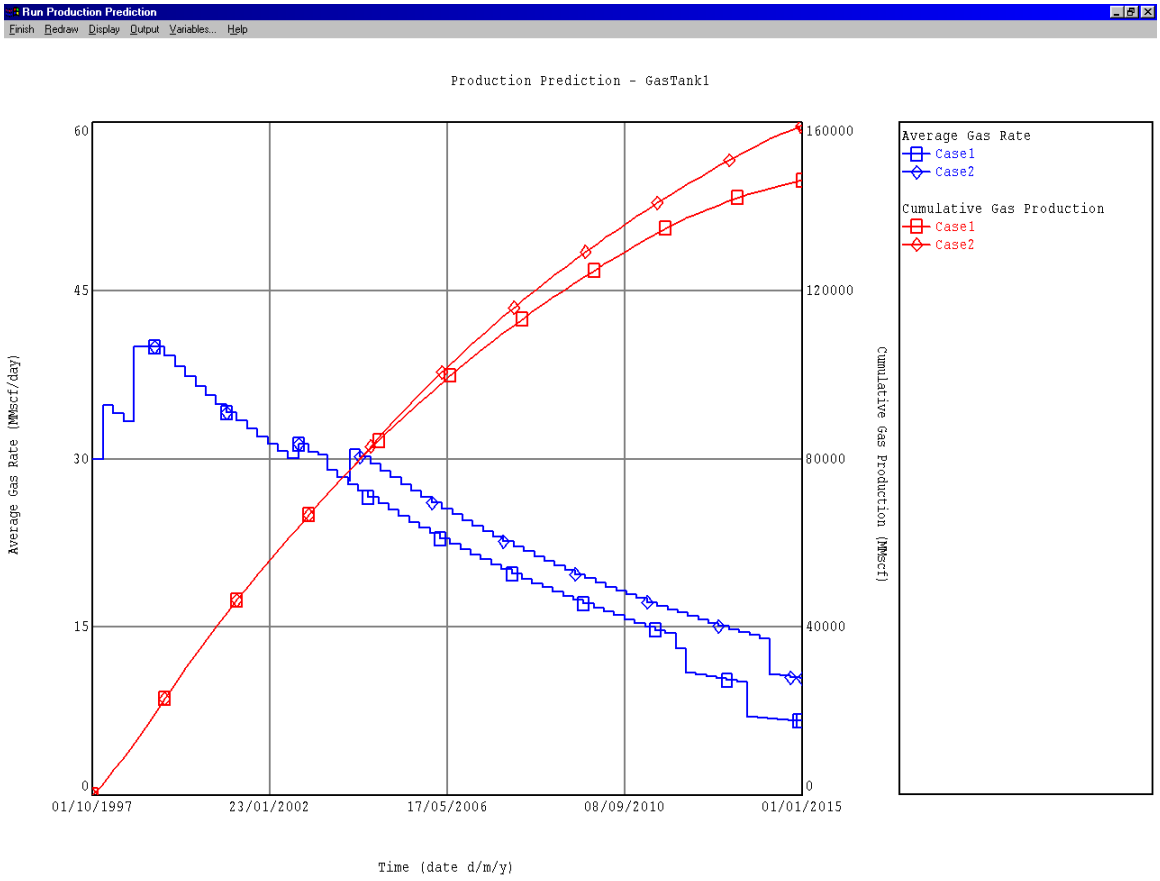


Figure 202: Average Gas Rate Plot for Case 1 and 2

This plot shows a comparison between Case 1 and Case 2.
The example is now terminated.